# REMEDIATION AND REUSE OF A FORMER MANUFACTURED GAS PLANT SITE IN CHAMPAIGN, IL

BY

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THESIS

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ABSTRACT

The purpose of this thesis was to review effective technologies for eliminating contamination associated with manufactured gas plant sites by using *in situ* remediation. Another aim was to speculate an adaptive reuse of the site through revelatory design such that it unfolds the history of manufactured gas plants as they existed in 1800s to mid 1900s and also to educate the public about the remediation processes implemented on the site. The thesis argues that excavation – transportation – land filling is not an environmentally sound approach to site remediation but is only a temporary solution.

Steps involved studying the timeline and site dynamics to understand the production processes and transformation of the site over nearly 8 decades of operation. Studying locations of each component of the gas plant and comparing them with current areas of contamination helped to draw parallels about the probable sources and structures causing contamination and health concerns. Horizontal and vertical mapping of toxic compounds clarified the extent of below ground contamination and migration over the years.

*In situ* remediation technologies were chosen based on nature and extent of contamination on the site. The techniques chosen were robust and capable of handling deep below ground contamination. Cost and temporal analysis were used to compare a range of techniques for their cost effectiveness and site clean up duration.

Speculative projections for the site were based on remediation needs and shaped the conceptual site design.  Possibilities of cultivating history and memory as part of the cleanup process were also tested with one scenario. Revelatory designs were proposed to function only for the time the remediation process was active or only a limited time after clean up.

The last part of the thesis addressed social concerns associated with exposure to contaminants during clean up. In addition, to give the site a regional context, it is proposed that since the site's location offered a unique advantage of connectivity to other towns, it could be part of a future recreation corridor. The study also has the potential to serve as a brownfield remediation and redevelopment primer for the 67 other manufacturing gas plant sites in the state of Illinois.

ACKNOWLEDGMENTS

Writing this thesis was a major undertaking, and I would not have been able to complete it without the assistance and encouragement from my friends, family, and professors. I would like to express my gratitude towards Professor David Kovacic, my adviser and committee chair, for his creative ideas and guidance through out the thesis development, presentation and writing. His scientific, technical and editorial advice helped me improve my thesis immensely. I also thank Assistant Professor Stephen Sears, my committee member, for his guidance during all phases of thesis work. His constant encouragement to broaden the scope of this thesis to make it unique helped me gain a new perspective on project designs.  I appreciate the invaluable resources and inspiration provided by Professor David Hays during research and design phases of the project and I would also like to thank Professor Elen Deming for providing valuable resources, guidance and motivation during initial phases of thesis development. I must thank Tim Bartlett and Martin Holland for their unconditional support and guidance through out my thesis.

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# Chapter 1: Introduction

Industrialization has been crucial for our advancement; however it has left us with legacy of environmental issues. A considerable part of the world's landscape has already been altered by man, because of industrialization. Brownfields are sites that are clear reminders of unsustainable human activities during this period. Research shows that 25,000 to 400,000 sites across the United States may be considered brownfields. These properties are found in small towns and rural areas throughout the U.S. (Russ, 2000).

Various definitions of brownfields are used to describe these toxic waste lands. The most prevalent has been defined by the U.S Environmental Protection Agency (EPA).

> "Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." (http://www.epa.gov/swerosps/ bf /glossary.htm)

Another definition put forth in 2001 in the US Small Business and Liability Relief and Brownfield Revitalization Act (Public Law 107-118, H.R. 2869, p.6) and signed into law in 2002 modifies the definition slightly.

> "Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant or contaminant" (DeSousa, 2008).

Thus, brownfield sites are abandoned or under-used properties where past actions have caused real or suspected environmental contamination. There is a change in the perception of such sites in recent times. Although they are classified as a subset of contaminated sites, these sites exhibit good potential for other uses and usually provide economically viable business opportunities. They are mainly located in established urban areas, where existing municipal services are readily available, or along transportation corridors. They may include, but are not limited to decommissioned refineries, railway yards, dilapidated warehouses, abandoned gas stations, former dry cleaners, and other commercial properties where toxic substances may have been stored or used (DeSousa, 2008).

Thus changed perception is included in the modified definition of NTREE (National Round Table on the Environment and the Economy, 2003).

> "Abandoned, idle or underutilized commercial or industrial properties where past actions have caused known or suspected environmental contamination, but where there is an active potential for redevelopment".

This change in perception places some value to these properties. It acknowledges that such rendered useless sites that are inevitably associated with blight and lower property values could be revitalized and included into cityscapes again. It is important to understand that these derelict pieces of land were once booming, productive, revenue generating industries that were very valuable to the society during the industrial revolution. We understand how indispensable and important such sites and industries associated with them were, if we study the past. An article in January 13th, 1868 issue of the Champaign, Illinois' News Gazette entitled *"Shall we have gas?"* reveals this for the site under study:

> "When shall a reservoir be filled, when shall pipes be laid, when shall we have more 'light'. Let us do something small even if we commence by doing a little. Decatur has invested in gas works and is glad of it. Centralia took stocks in gas works and finds that it pays, increases the value of the property and is great convenience".

It is very important to note here that at that point in time, cities were ready to invest in new gas plants and new developments to increase their standard of living and to foster economic growth. However, we cannot deny that these developments brought with them environmental problems and concerns that were left for the following generations to solve. With a contaminated site or a brownfield nearby people can be exposed to a wide range of toxic compounds through the ingestion of polluted soil directly or indirectly through food produced on or near these properties; through inhalation of airborne particulates that volatilize from soil or abandoned chemicals, and from direct skin contact with contaminated water or air borne particulates. The contaminated soil and ground water that may be contained in these properties can pose a wide variety of risks to human health and the environment depending on their toxic properties, route of exposure (mouth, lungs, or skin), duration, and quantity of exposure. Thus, brownfields stand as both an opportunity for recovering urban land and as a reminder of the harmful and wasteful practices of the past that need to be addressed (Russ, 2000).

This thesis was developed to determine appropriate remediation technologies for the cleanup of a 2.5 acre brownfield site in Champaign, IL; where a Manufactured Gas Plant (MGP) was operational from the 1860s to the 1930s. MGPs used coal as a raw material to manufacture gas which was used as a fuel for cooking, lighting and heating purposes. By the later half of the $19^{th}$ century most of the big cities in the U.S had commissioned these plants. By 1950, however, natural gas replaced the dirtier MGP technology. As natural gas became widely available, MGPs closed leaving large areas of abandoned and eventually derelict land contaminated with coal tar related MGP wastes. The thesis also strives to propose an unconventional end use for the site such that it lets visitors to the site, unfold the history and dynamics of the manufactured gas plant. The end uses proposed will also give visitors information about the site's recent history as a brownfield. Visitors will learn about the remediation processes implemented on the site to ensure complete removal of contaminants and make it usable once again.

This thesis is composed of the following chapters. *Chapter 2* gives an overview of manufactured gas plants, history of their demand in the U.S, their growth, decline, demise and period of environmental concern, and associated generic hazardous wastes and toxic compounds. *Chapter 3* covers Literature Review. *Chapter 4* describes the location and history of the brownfield site under study, and the dynamics of installation, expansion and demolition. *Chapter 5*; Mapping Contamination describes presence of contaminants and their location on the site. The study maps the vertical and horizontal extent of contamination and their concentration as found on site. The quantitative analysis is done by using comprehensive site investigation reports available at Douglass Library, Champaign IL. Clean up processes and procedures for the site delineated by Ameren IP are further discussed in this chapter. Technologies have been screened and chosen to address the 30' below ground surface (bgs) contamination. The details of technologies identified, and examples of successful projects are presented in *Chapter 6*. It is very important for the proposed techniques to be both cost effective and efficient. Cost comparison and analysis of proposed technologies is presented in *Chapter 7* to give the reader an idea about the technologies that are both efficient in remediation and cost effective. Chapter 8, *Discussion* is the final chapter and presents speculative projections and scenarios for two technologies chosen for further study: Dynamic Underground Stripping and Stabilization/ Solidification. These technologies will be used to reveal to visitors the history of the site and remediation processes at work. The third technology chosen for remediation was land farming but since it involves significant earth moving and dust, no interim scenarios or revelatory designs are proposed for this technology. Social concerns are addressed to discuss the implications of revelatory designs and ways in which fear and anxiety about personal safety while visiting the site during treatment processes could be handled. The purpose of proposing revelatory designs is to educate people and remove misperceptions associated with toxic sites. The final chapter is followed by summary of thesis and appendices.

# Chapter 2: Overview of Manufactured Gas Plants

**Part I**

**Growth, Decline, Demise and Environmental Concerns of MGPs**

Manufactured gas was perhaps one of the most important drivers for the industrial revolution. Having spanned around 150 years of human technical achievement, it now presents unique remediation challenges to both government and the utility industry it spawned at the beginning of the Industrial revolution. In this time, an unusual array of invention and economic forces played back and forth across this dynamic industry. The manufactured gas industry was also ever-changing. Technological inventions promised better fuels like electricity and natural gas, and manufactured gas plant industry faced continuous threat from its competitors. The economic competition drove gas prices lower and lower; and coal strikes, financial panics, depressions, war and other causes perturbed their operations (Hatheway, 2006).

Coal gas was made primarily from coal, as well as many other organic feed stocks. During the gas manufacture, tars were created and leaked, spilled or discharged to the environment. These tars are not susceptible to natural degradation and therefore have lives that will extend into geologic time (Hatheway, 2006).

**Growth of Manufactured Gas (1850-1876):** During this period there was an increase in demand for manufactured gas for expanded street and commercial lighting in almost all of America's major cities. By 1850, towns with a population of more than 10,000 had invested in gas works.  At the same time, gas producers provided manufactured gas to power gas engines and to supply fuel for various industries. At this time litigation also began to appear in the US related to environmental problems from uncontrolled discharge of gashouse wastes (Hatheway, 2006).

**Decline of Manufactured Gas (1920-1940):** As the First World War came to an end, the manufactured gas industry continued to suffer feedstock shortages needed for manufacture of gas. Hatheway (2006) states, “Utility holding companies thrived and gas works changed hands frequently, generally being consolidated into larger central stations with gas distribution through radial networks of higher-pressure pipes further into the suburbs”. New gas plants were however still built to provide manufactured gas to smaller businesses and towns. The gas industry, through its American Gas Association (1919), carried out continued national action in defining environmental effects of specific gas-house wastes. There was widespread awareness of the toxic effects of MGP wastes and many states enforced acts to check the quantity of gas-house wastes discharged into the environment.

**Demise of Manufactured Gas (1941-1966):** The federal government financed huge oil pipelines from the oil fields of Texas to the industrial northeast as wartime defense measures. After the war ended, these pipelines were sold to the natural gas industry which consequently led to a wide-scale closure of manufactured gas plants in the larger eastern markets. Huge and reliable natural gas fields discovered at the same time led to further take over of the market areas for natural gas. The last manufactured gas plants were shut down by 1966, while only a few continued production through the 1990s (Hatheway, 2006).

**Rise of Environmental Concern (1965-Present):** The State governments were funded by the Federal government, to deal with water pollution control issues. The Air Pollution Control Act of 1955 was the first United States Clean Air Act enacted by Congress to address the national environmental problem of air pollution and the 1972 Clean Water Act was passed with the goal of removing high  amounts of toxic substances from water. This was in tandem with the investigations led by experts throughout the US who identified that manufactured gas plant coal tar emissions were the nation's major source of air pollution. They also identified coal tar as the major source of ground water pollution. Since 1965, studies have been under way to determine the transport and fate of these compounds in the environment (air, soil and water), health concerns associated with their exposure, and ways to permanently remove them from their place of generation. (Hatheway, 2006).

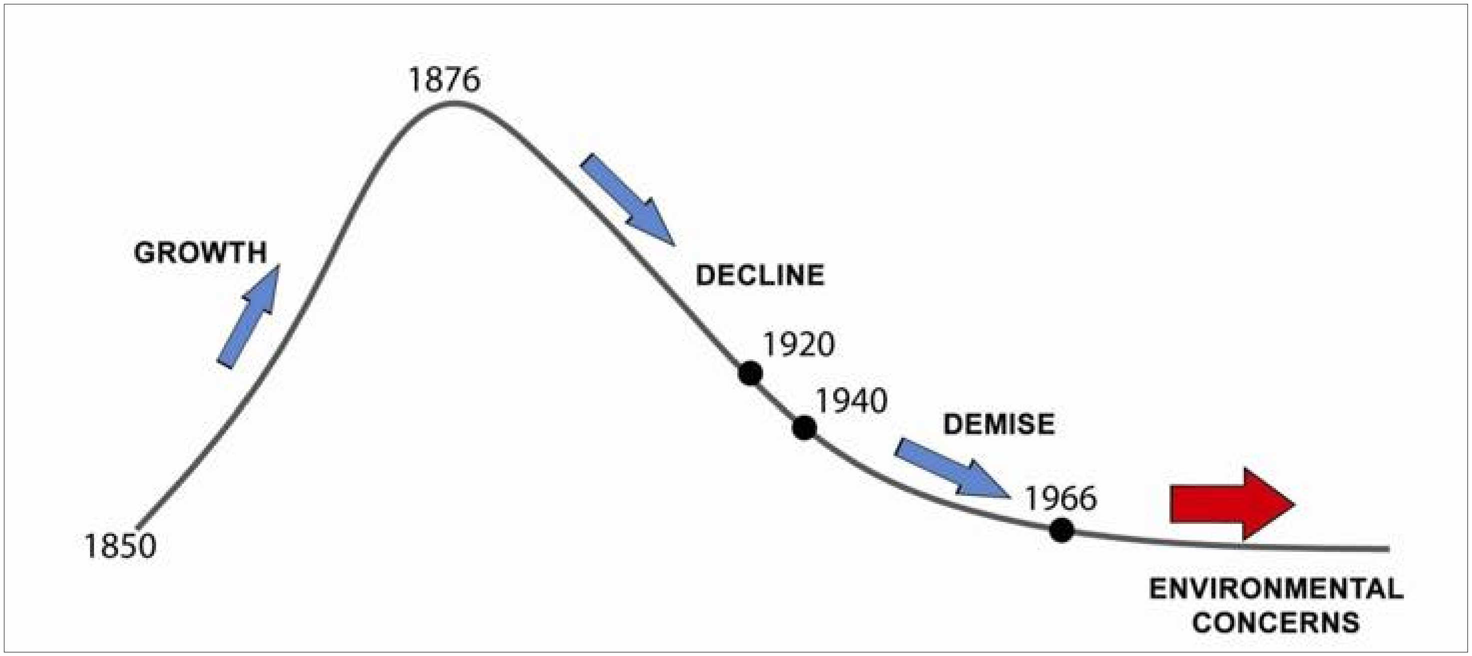



**Figure 1: History of Manufactured Gas Plants in the U.S.**

**Part II**

**Generic Former Manufactured Gas Plant (FMGP) Wastes: Environmental Threats.**

Gas works wastes had to be managed exactly on the day of their creation. Gas works management had to make a choice of waste management fate, as required by their circumstances. So wastes were burned as fuel, stored, recycled, treated, dumped, transported, and discharged to the ground (Hatheway, 2006).

The most common and environmentally significant form of waste from the tar plant was coal tar. Tars are composed of 500 to 3000 different compounds, known to be toxic to humans, mammals, and plant life. Sometimes carcinogenic, these tars are denser than water, thus tending to sink into the groundwater environment where they contaminate passing ground water.

Following is a list of gas works solid wastes typical of what can be found at FMGPs, where wastes were dumped onsite.

**Table 1: Generic Manufactured Gas Plant wastes (Hatheway, 2006).**

| **Generic FMGP Hazardous Substances** | | |
|---|---|---|
| **Residual** | **Origin in Manufacturing** | **Present-Day Environmental Implication** |
| Coke | Residue of coal-gas coal charge | Is found as sorbed contamination under certain FMGP conditions |
| Ammonia | Coal-Gas generation | Generally dissipated over post-operational decades, but could emerge to endanger those involved in excavation or whom enter gaining leaks to sewers |
| Ash | Waste from generator feedstock | Low absorptive capacity for PAHs; Generally dumped around the plant or in off-site dumps |

**Table 1 (continued)**

| | | |
|---|---|---|
| Liquor | Wash water effluent from cleansing | All forms tend to have dropped PAHs in tar form in surface watershed or subsurface aquifer matrix; Emulsions typically have a long, undegraded life |
| Tar | PAH residue as a whole formed as a waste product | Have a long undegraded life and a major concern for health |
| Tar Sludge | PAHs containing ash | Any of such, when in the groundwater environment have the capacity to further contaminate bodies of ground water entering into contact with these gas-house wastes |
| Scrubber Packing | Generally wood chips | Scrubbers commonly were packed with wood chips as an adsorption medium |
| Box Waste | Media from purifying boxes, as removed and disposed off from standpoint of being "spent" and no longer capable of purification | Always considered environmentally dangerous from standpoint of adsorbed PAHs, cyanide, sulfur as well as arsenic and other heavy metals |

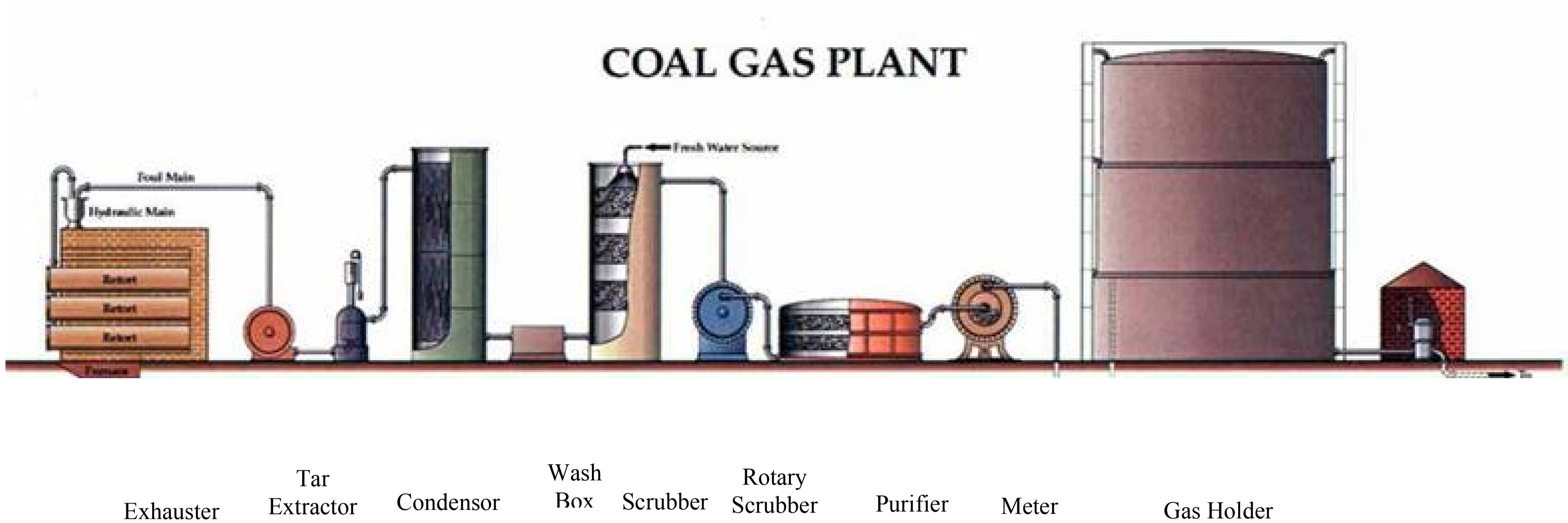



**Figure 2: Typical manufacturing gas process diagram** (Image source: http://www.hatheway.net/03gas plantcomponents.htm).

# Chapter 3: Literature Review

Several key concepts have framed this thesis. It has grown out of a desire to interweave concepts in Environmental Chemistry, Environmental Remediation, Landscape Architecture, Systems Thinking and Design. Inspiration was drawn from several well known artists, and landscape architects- designers like Niall Kirkwood, Kathrine Gustafson, Julie Bargmann, Maya Lin, Patricia Johanson and Jeanne Claude.

## KEY CONCEPTS IN ENVIRONMENTAL CHEMISTRY:

Research was done to understand properties of Manufactured Gas Plant (MGP) toxic compounds and their fate and behavior in the environment. Soil and groundwater contamination problems exist at many former manufactured gas plant sites because of prior process operations and residuals management practices. These process residuals are dominated by six primary classes of chemicals: polycyclic aromatic hydrocarbons (PAHs), volatile aromatic compounds, and phenolics, inorganic compounds of sulfur, nitrogen, and metals (Luthy et al., 1994). Light oils (VOC, PAHs, Benzene, Toluene, Ethyl benzene and Xylene, also called BTEX compounds collectively) are generated in far larger quantities (10-100x more) than heavier tar oil, and are the only organics that travel extensively. Light oils are known to reach several kilometers underground and precipitate the carried heavier fractions of PAHs (Hatheway, 2006).

Each MGP site has unique characteristics; similar patterns of soil contamination can be derived from combining information about several MGPs that leads to a similar pattern. Evidence of these similarities has become apparent over the past several years as the Gas Research Institute (GRI), the Electric Power Research Institute (EPRI), and others have investigated the technical aspects of MGP site management (Luthy et al. 1994).

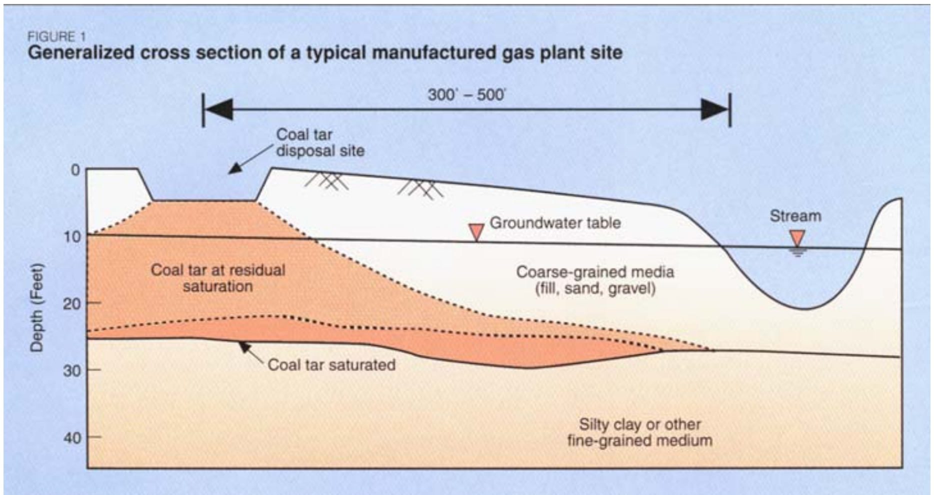



**Figure 3: A subsurface cross section of a typical MGP site** ( Image source: Luthy et al., 1994).

Chemicals associated with MGP waste include volatile organic compounds (VOCs) like benzene, toluene, polynuclear aromatic hydrocarbons (PAHs) like naphthalene, and tar acids like phenol and cresol, creosote and coal tar pitch, trichloroethylene (TCE) and polychlorinated biphenyls (PCBs). These are complex chemical compounds and have a potential to cause severe health concerns. Of particular importance from an environmental standpoint, is the presence of PAHs at MGP sites. The primary source of PAHs at MGP sites are typically tars and lamp black. Due to the acute and chronic systemic toxicity associated within lower molecular weight PAHs and the potential carcinogenicity associated with the higher molecular weight PAHs, the EPA has designated sixteen PAHs as being environmentally important and representative of PAHs as a class of compounds. While many other PAHs exist, this EPA list defines the subset of most concern to the management of MGP sites. Apart from these, other chemicals of concern are BTEX compounds and metals like arsenic, cadmium and iron (Luthy et al. 1994).

**Table 2: Environmentally Important Polyaromatic Hydrocarbons.**

| Environmentally Important PAHs | | | | |
|---|---|---|---|---|
| **Two-ring** | **Three-ring** | **Four-ring** | **Five-ring** | **Six-Ring** |
| Napthalene | Acenaphthene | Benzo - (a)anthracene | Benzo (b) - fluoranthene | Benzo (g,h, i) perylene |
| | Acenapthylene | Chrysene | Benzo (k) - fluoranthene | Indeno(1,2,3-cd) pyrene |
| | Anthracene | Fluoranthene | Benzo(a) pyrene | |
| | Fluorene | Pyrene | Dibenzo(a,h) - anthracene | |
| | Phenanthrene | | | |

According to DeSousa (2008), the major types of health risks associated with contaminated sites are, incremental cancer cases (all types of cancer) and non-cancer hazards like respiratory, neurological, reproductive effects.

Further, Comprehensive Site Investigation (CSI) report (2008) produced by Ameren IP was referenced to determine vertical and horizontal extent of contamination on site. Concentrations reported at specific sampling locations could be studied keeping in mind site geology and relative gas yard layout. This can lead to an advanced understanding of the entire contamination situation that can be used in the development of the site remediation plan (Hatheway, 2006).

It is clear that much information about site contamination can be obtained from comparisons of the relative nature, position, and concentration magnitudes of different MGP contaminants. The most important rule of consideration is the assessment of contamination in terms of individual “hot spots” of contamination and how they relate to likely points of generation in the gas-manufacturing process at that time. This may give essential insight in to how they came to be in their respective locations, and in what ways their presence may lead to continued contaminant transport or release to the environment or to potential human receptors, now (Hatheway, 2006).

KEY CONCEPTS IN REMEDIATION TECHNOLOGIES:

Onsite and *in situ* treatment techniques have found wider acceptance among brownfield stakeholders. Remediation schemes should be chosen to suit to the circumstances of a particular site in order to achieve cost-effective solutions to complex problems. The solutions differ based on use of the site and its history and may range from an old mining works to oil refinery to a gasification plant, or a gas service station and so on (Ellis, 1992). The technologies that have been employed at the MGP sites have been divided in to 3 broad categories: Excavation and Treatment/Disposal, containment and *in situ* remediation; and Extraction and Recovery technologies (Owen, et. al., 1998).

The report, *A survey of MGP Site Remedial Technologies* (Owen, et. al., 1998) states that excavation and offsite land filling had been performed at a majority of MGP sites at which remedial activities have been conducted. *In situ* treatment was not applied at MGP sites extensively till the late 1990s but the recent promulgation of LDRs (land disposal restrictions) has made utilities rethink cleanup technologies. The main benefits of *in situ* remediation systems over conventional methods are the lower final cost for remediation, minimum cost for operations and maintenance, no moving parts that could break and no discharge permits", or waste disposal of liquids for *in situ* groundwater treatment. According to the report on MGP characterization of wastes, i*n situ* technologies in contrast to past methods of disposal that often involved sending wastes to landfills where responsible parties continue to bear long-term responsibility for the wastes environmental and health effects, eliminate the threat of chemicals substantially (EPA, 1999). Owen et. al (1998) state that, as for any site clean up selection, costs have played an important role in the selection of remedies for MGP sites. Costs are typically factored into the decision initially at the feasibility evaluation stage.

Much interest has developed around using treatment train technologies to make remediation solutions even more effective. The EPA Brownfields technology primer (2001) states that according to cost savings and treatment effectiveness point of view, it is often advisable to combine, spatially and/or over time, different treatment technologies into a unified cleanup strategy. Treatment train technologies are implemented in cases where no single technology is capable of treating all of the contaminants in a particular medium or where one technology might be used to render a medium more easily treatable by a subsequent technology. Phytoremediation is a technology that can provide benefit when used in concert with more intensive and therefore more expensive technologies. It thus reduces overall project costs, while achieving cleanup goals.

## REVELATORY DESIGNS AND ROLE OF LANDSCAPE ARCHITECTURE

Manufactured sites can be viewed with an approach to revive polluted urban sites. This approach looks to the dynamic nature of the existing physical site conditions, and the combination of clean-up and engineering technologies with design approaches to guide development. The logic and requirements of a technology can motivate thinking about conceptual site design. Experiential and visual clues can be drawn from technologies and these in turn can begin to inform design proposals. The interaction of technologies with progressive landscape design practices can be used for orderly creation of future sites (Kirkwood, 2001).

Daniel Bluestone (2007) states that people involved in the cleanup of contaminated sites could make their efforts more comprehensible and less scary to the public if they could reveal how the flows of materials and pollutants on toxic sites had actually taken place. One example of revelatory design is artist Mel Chin's *Revival Field* in St. Paul, Minnesota. In 1990 he became involved in the process of using plants to detoxify waste site as implemented through his artwork on a 300 acre landfill. After the implementation *Revival Field* was seen as an important prototype for remediating land using ecological art. Referring to Chin's work Matilsky (1992) states that, working with toxic wastes involves applications of permits, negotiations with public officials, and the risk of exposure to contaminants. Also the fact that an artist was able to overcome all of these hindrances opens up yet another dimension to ecological art. Chin's work illustrates the need for diverse professions to be involved in the cleanup of toxic sites and in the pioneering of ideas that integrate sound ecological approaches with increased public involvement and awareness.

## REGIONAL CONTEXT

Brownfields are an inevitable part of any post industrial landscape. The brownfield site is continuous with the fabric of the city. Neither natural nor urban systems can ever afford to be wholly exclusive, whatever the given definition of nature or the city (Gans, 2004). Berger (2008) stated that the vast array of environmental – reclamation science and technology is not sufficient as the degraded environments we address are cultural artifacts as much as they are problems for science.  So we must address these problems with the full range of arts and humanities, as well as the sciences, if we were to be effective. Waldheim (2006) noted that the idea of traditional way to value urban landscapes is through 'place making' is now blurred and that the cityscape is fragmented and chaotically spread, escaping wholeness, objectivity, and public consciousness- *terra incognita*. He further continues to say that this condition begs for landscape architects and other designers of the urban realm to shift their attention away from small-scale site design in order to consider how we can improve regional landscape of the cities (Waldheim, 2006).

# Chapter 4: Site Location, History and Dynamics

**Location and Context:**

The brownfield under study is within the city limits of Champaign, IL in Champaign County, with the site address: 308 N. 5th Street, Champaign, IL 61820. The property is currently owned by Ameren IP. A rail road right-of way borders the site to the North. It is an active track and is occasionally used for freight train traffic. The site is surrounded by residential properties to North, South and West and by commercial properties to the east. Vacated 6th street right-of-way is adjacent to the east of the site; however 6th street is abandoned between the rail road right of way and alley south of the site. The property east of the vacated 6th street right of way is commercial. North 5th street borders the site to the west, and at one time, Hill Street approximately bisected the site in the east- west direction but now is the part of the site and owned by Ameren IP.

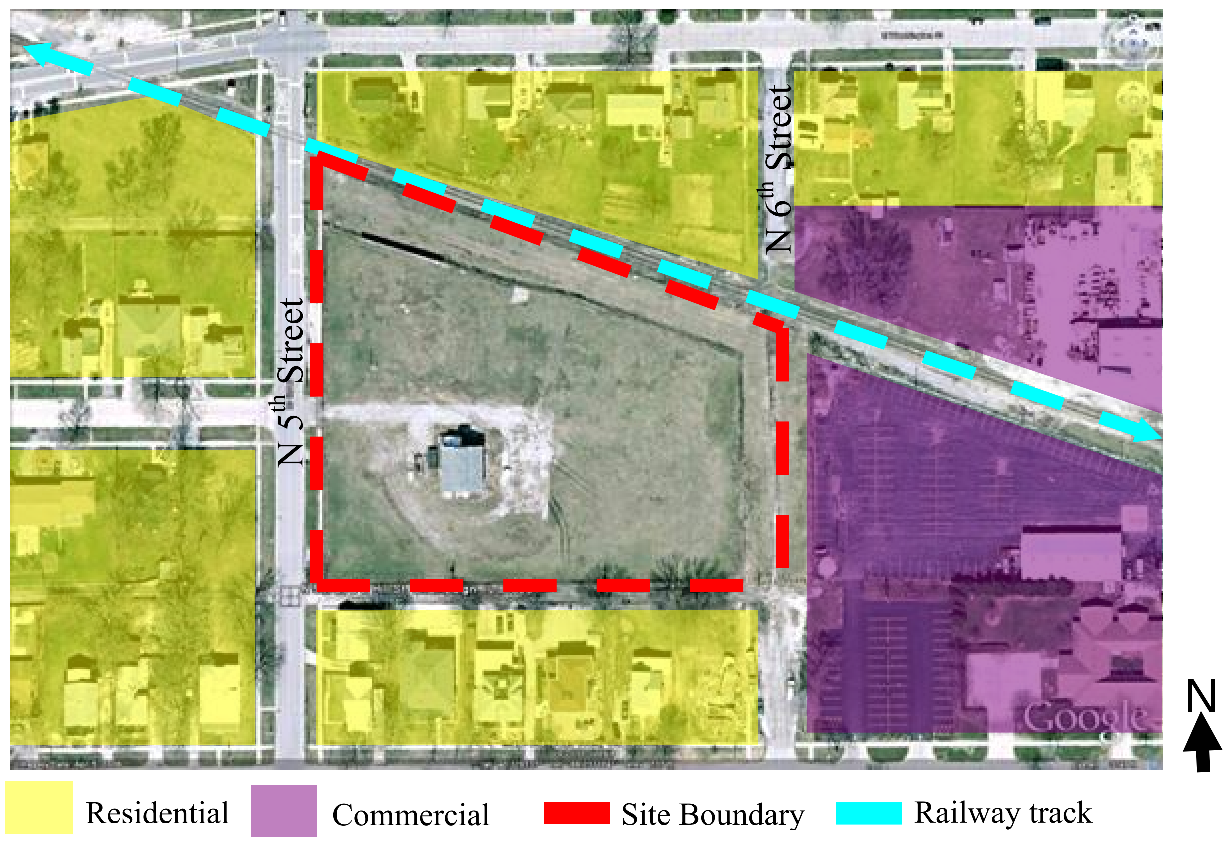



**Figure 4: Site Location and Boundary** (Image source: Google Earth).


**Figure 5: Site Location of Champaign Manufactured Gas Plant** (Image source: maps.google.com).

**History and Dynamics:**

Historical information suggests that the original MGP at the site began circa 1869 and continued through approximately 1933 (Comprehensive Site Investigation Report (CSI), 2007).


**Figure 6: Panoramic View of the Gas Plant (1869).** Note that the site was located at the edge of the town (CSI, 2007).

The panoramic drawing illustrating the gas plant as in 1869 (Fig.6) was taken from a bird's eye view of the city of Champaign originally published by Chicago Lithograph Co. Records for the site prior to 1887 are extremely limited; however, the first edition of Brown's Directory (1887) indicates that the Champaign and Urbana Gas Light Co. was producing coal gas at the site (CSI, 2007). Sanborn maps are available from the year 1887 (Fig.10).

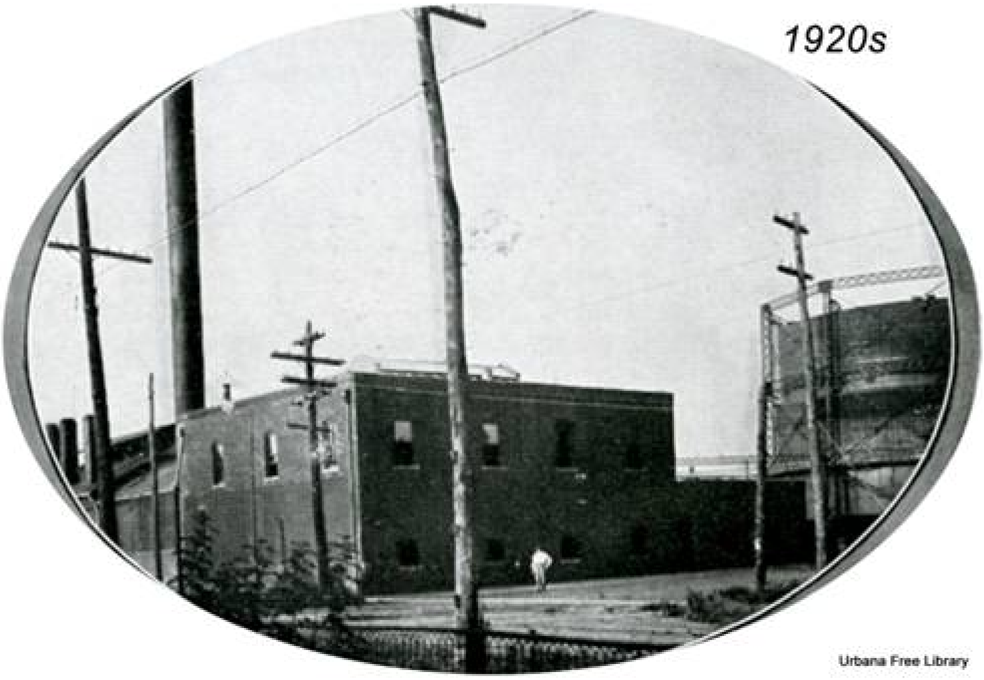



**Figure 7: Champaign MGP in 1920s.** Note the gasometer to the far right of the photograph (Image source: Urbana Free Library).


**Figure 8 : Champaign MGP site showing booster house in 2007.**
Photo taken from 5th street looking east (Image courtesy: Prof. Stephen Sears).

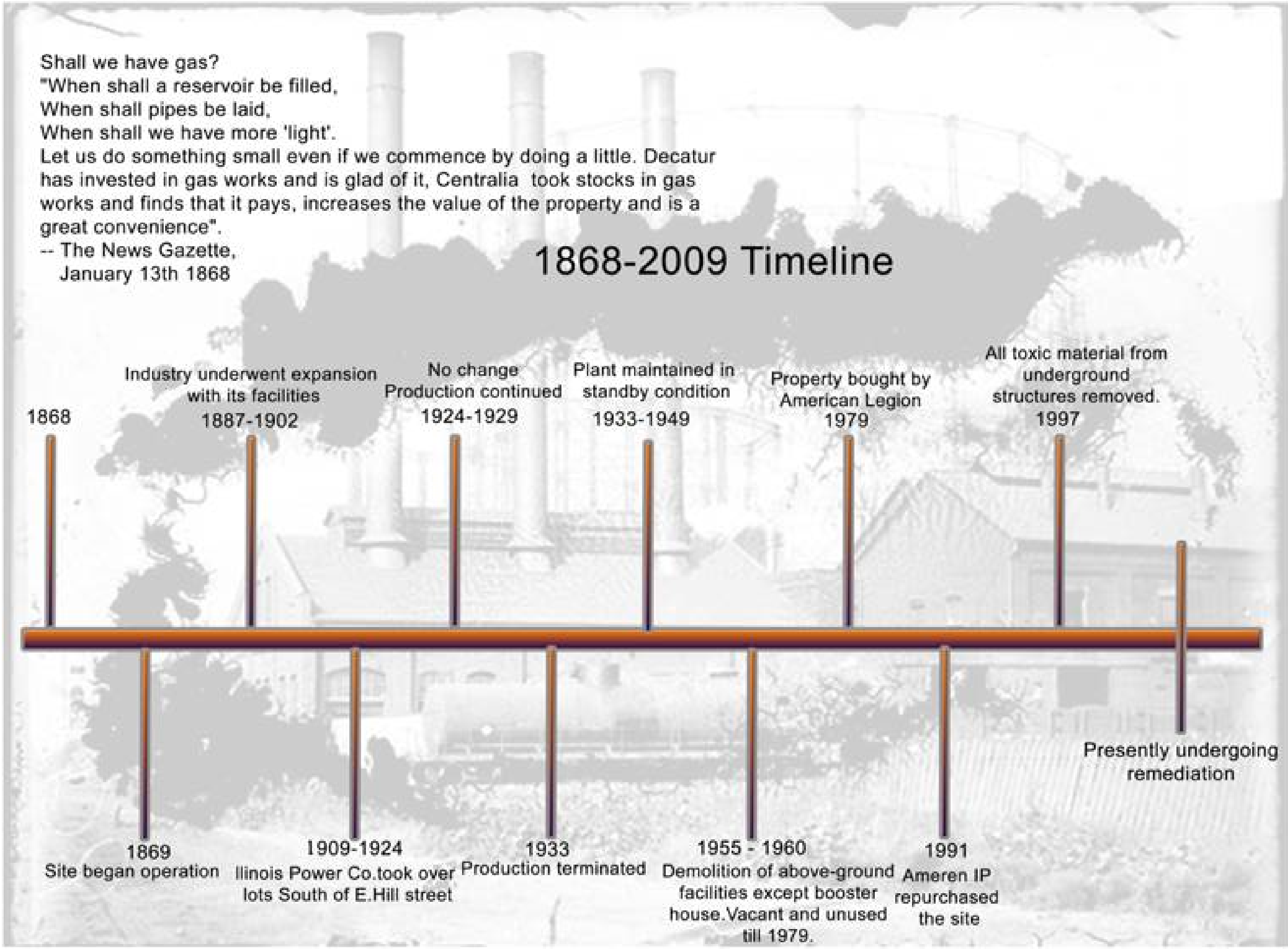



**Figure 9: Time line showing important dates from beginning of plant operations to its shutdown followed by remediation activities as of today** (Background Image source: Google Images).

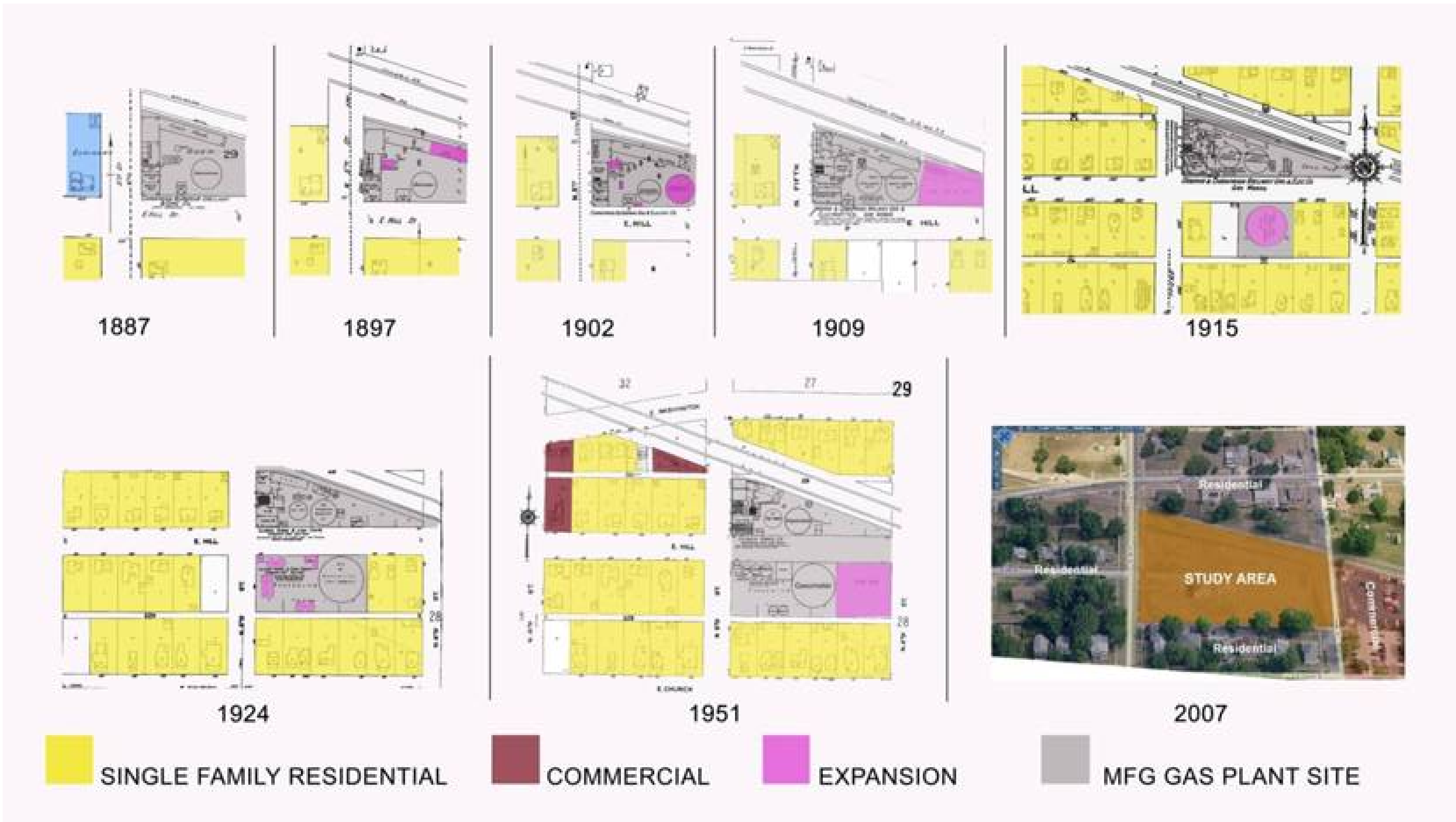



**Figure 10: Site Dynamics, with the expansion areas shown in magenta color** (Image Adapted from Digital Sanborn maps- http://sanborn.umi.com).

- 1887: Sanborn map illustrates the facility layout and shows a single gas holder (23,000 cubic feet) or gasometer, coal shed, retorts, lime house, two wells, and condensing, purifying, and meter rooms.
- 1897: Sanborn map shows expansion in the form of a pipe fitting room and a core crusher area.
- 1902: Little extra sheds are added to the site near the oxide shed and coke crusher. Gasometer installation is a major addition to the plant with an increased capacity (49000cu.feet) indicating increase in production of coal gas during that time.
- 1909: The site expands further as shown with the area added for storing coke pile. The holding capacity of gas retainers or gasometers was increased this year again from 23,000 to 25,440 for gasometer 1 and from 49,000 cu.feet to 100, 699 cubic feet for gasometer 2 indicating increased production and probably popularity of coal gas during that time.
- 1915: The Company expands to south buying 2 residential lots across E. Hill Street to install a third gasometer, with a capacity of 500,000 cu.feet.
- 1924: Sanborn shows more expansion; three lots west of the third gasometer for meter shop, 2 gas purifiers, 2 fuel tanks a shed.
- 1951: In between 1924 and 1929 meter shop south of E. Hill Street is shown to be removed according to Sanborn map. Coal yard is introduced for temporary storage of coal (CSI, 2007).

The production of gas on regular basis was terminated around 1932. The plant was maintained in stand by condition through 1949. In 1959 all structures north of Hill Street right of way had been removed. According to the report, "Based on interviews with Ameren IP employees, demolition of the above ground on-site facilities, with the exception of the booster house, occurred between 1955 and 1960. The site remained vacant and unused from 1960 until the property was sold to American Legion Post in 1979. The American Legion Post renovated the interior of the booster house and used it for periodic meetings. The structure was used and maintained by the American Legion from 1979-1991. While regarding the site for surface drainage, workers at American Legion found impacted soil and encountered tar-like odors after which Ameren IP was notified. Ameren IP then bought the property back in 1991and started monitoring and analysis of soil, ground water and air to assess the level of risks associated with these odors. The site has remained vacant thereafter (CSI, 2007).

In conclusion, the plant operated from 1869 to 1930s. Before its demolition, two below ground gas holders, one above ground gas holder, 5 tar wells, a tar separator, seven oil tanks, and two diesel fuel tanks were present, and all aboveground structures, except for the booster house, were demolished in the late 1950s.

# Chapter 5: Mapping Contamination

A comprehensive site investigation (CSI) report was prepared by Philip Services Corp. for Ameren IP in 2007. The CSI analytical program was developed with a primary objective to provide sufficient analytical data to delineate environmental impacts and to facilitate comparison with Tier 1 Remediation Objectives (ROs) (CSI, 2007). Before mapping contaminants, it is imperative to know specific meanings of terms used in this context. Following are short definitions of terms frequently used in this chapter.

Contaminants: They are toxic compounds that pose an unacceptable threat to human health and/or the environment (EPA, 2009).

Contaminants of concern (COC): A contaminant becomes a contaminant of concern when it occurs at a concentration that poses an unacceptable threat to human health and the environment. The RBCA (Risk-Based Corrective-Action) program will establish that particular concentration limit specific to land use and exposure scenario (EPA, 2009).

Risk-Based Corrective-Action: RBCA refers specifically to the standard entitled *Guide for Risk-Based Corrective Action Applied At Petroleum Release Sites* [E-1739-95] that was published by the American Society for Testing and Materials (ASTM) Subcommittee on Storage Tanks (EPA, 2009).

Tier 1 Remediation objectives: According to EPA, "a Tier 1 evaluation compares the concentrations of contaminants of concern detected at a site to baseline remediation objectives. Tier 1 enables site owners to choose between residential and industrial/commercial use of a site; however, institutional controls are required whenever remediation objectives are based on an industrial/commercial land use.

Tier 1 provides different remediation objectives based on the exposure pathway.

- Residential Soil Remediation Objectives
- Industrial/Commercial Soil Remediation Objectives
- Groundwater Remediation Objectives

"Residential Property" is any real property that is used for habitation by individuals or properties where children have the opportunity for exposure to contaminants through ingestion or inhalation at educational facilities, health care facilities, child care facilities or playgrounds. "Industrial/Commercial Property" is any real property that does not meet the definition of residential property, conservation property or agricultural property. Whenever using the industrial/commercial scenario, the Construction Worker Scenario must also be evaluated. If the construction worker objectives are more stringent than the industrial/commercial objectives, the construction worker objectives apply. The construction worker scenario is designed for workers performing demolition, earth moving or construction activities, as well as routine and emergency utility installation or repair. Groundwater Remediation objectives are used when ground water is used for potable or any other purposes for daily use. Of the three exposure routes, the most restrictive becomes your site's soil objectives. A contaminant is not of concern if the concentration of the contaminant is below the Tier 1 objective for the most restrictive route (Residential/ Industrial/ Groundwater). Thus, if the actual concentration does not exceed any RO, then the site owners can ideally be eligible for "No further Remediation" letter from IEPA"(http://www.epa.state.il.us/land/taco/6-tier-1.html).

Along these lines it could be inferred that remediation objectives for "Construction Worker Scenario" Remediation objective should be followed for the site under study. However, to avoid complexities of information about exposure route, this thesis takes in to consideration the most restrictive remediation objective, for comparison with existing contaminant concentration. According to IEPA this RO is for ground water remediation and so the maximum allowable values for each contaminant on the site are lowest which ensures minimum health concerns among all 3 exposure pathways (http://www.epa.state .il.us/land/taco/6-tier-1.html).

MGPs are known to be associated with complex organic compounds. Table 3 shows major contaminants of concern found at the site under study, and includes a brief description of their health concerns.

**Table3: Major contaminants of concern.**

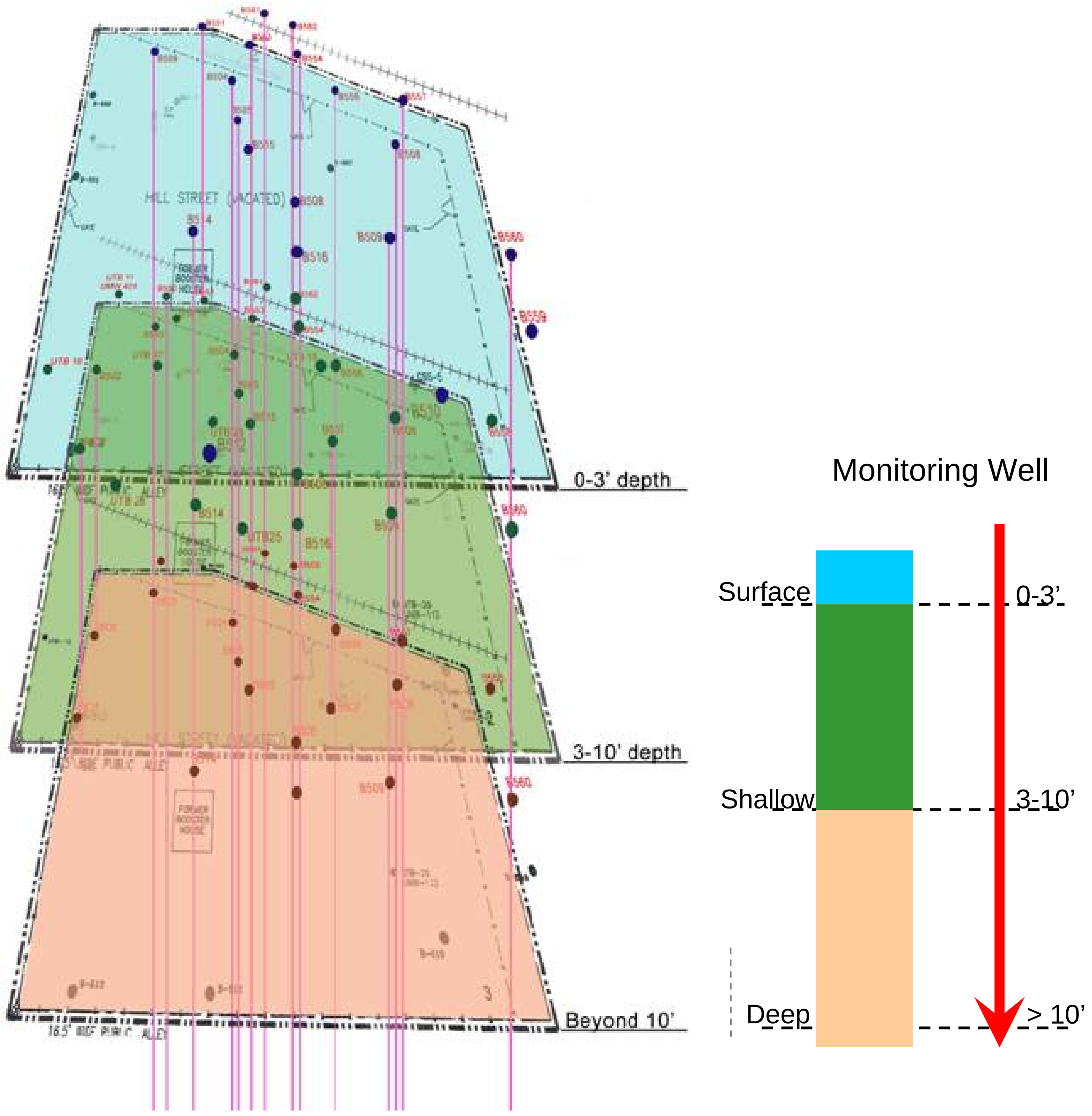
| No. | Contaminant of Concern | Health Concerns |
|---|---|---|
| 1. | Benzene | Known to depress the immune system, leukemia, blood cancers, targets liver, kidney, lung, heart and the brain. |
| 2. | Toluene | Respiratory tract irritant, decreased blood cell count, Liver and kidney damage, may affect the developing fetus. |
| 3. | Ethyl-benzene | Eye and throat irritant, Irreversible damage to the inner ear and hearing, possible human carcinogen. |
| 4. | Xylene | Exhibits neurological effects, irritation of the skin, eyes, nose, and throat, difficulty in breathing, delayed growth and development |
| 5. | Chrysene | Possible human carcinogen |
| 6. | Napthalene | Known to damage red blood cells, possible human carcinogen. |
| 7. | Phenanthrene | Suspected to cause tumors, reproductive problem, and damage to skin, body and immune system. |
| 8. | Benzo (a) pyrene | Mutagenic and highly carcinogenic, known to cause genetic damage, malignant lung tumors. |
| 9. | Benzo (a) anthracene | Suspected carcinogen |
| 10. | Benzo (b,k) fluoranthene | Suspected carcinogen |
| 11. | Dibenzo (a,h) anthracene | Possible human carcinogen, suspected to cause leukemia and mammary tumors. |
| 12. | Indeno pyrene | Shown to produce harmful effects on the blood, bone marrow, spleen, and lymph nodes, interferes with metabolism |

The most commonly occurring contaminants are BTEX and PAH compounds. PAH compounds differ from BTEX compounds in that they are three- ring benzene compounds rather than one as in BTEX and are characterized by more complexity and high persistence in the environment.

According to IEPA's Tiered Approach to Corrective Action Objectives (TACO) guidance, the soil sample analytical data was divided in to three groups. These groups include surface soils, (0-3 feet bgs), shallow subsurface soil (3-10 feet bgs) and deep subsurface soil (greater than 10 feet bgs) for all contaminants monitored. According to the CSI report, three types of soil sampling were done on site.

1) Surface soil samples: are defined as soils collected from ground surface to a depth of 3 feet bgs (below ground surface)
2) Shallow subsurface soil samples: are defined as soils collected from 3 feet bgs to 10 feet bgs.
3) Deep subsurface soil samples: are defined as soils collected from a depth of greater than 10 bgs (CSI, 2007).

Twenty six (26) probe holes were used to take duplicate samples for all 3 depths. Soil samples (more than 100 in number at various depths) were analyzed for BTEX and PAH compounds. Huge data sets measuring the vertical and horizontal extent of contamination were condensed to make them visually comprehensible and to more readily understand the available information. Following are some tables and images that communicate in brief the qualitative, quantitative and spatial analysis of contaminants found at this brownfield site. Figure 11 shows a visual representation of the vertical extent of contamination. Dots represent monitoring well locations. These dots are joined indicating presence of contaminants at levels; 0-3, 3-10 and beyond 10' soil. It is inferred that very few lines end at second level (shallow subsurface), but most extend to the third level indicating that the contamination has reached deep below ground up to and exceeding a depth of 28' (CSI, 2007).




11(A) 11(B)

**Figure 11: Mapping Contamination.** This is a visual representation of the vertical extent of impact of contamination. Samples were taken at three depths (surface, shallow, subsurface soils) as shown in figure 11(B). Dots in figure 11(A) represent monitoring well locations. These dots are joined indicating presence of contaminants at levels; 0-3, 3-10 and exceeding 10' below soil. Most lines extend to the third level indicating deep soil contamination.

For the purpose of this thesis, the readings tabulated here are maximum concentrations of BTEX compounds as recorded in the comprehensive site investigation report; taken at each monitoring well for each group: surface, shallow subsurface and deep sub surface. From the comprehensive site investigation report, data was screened for maximum Benzene, Toluene, Ethyl benzene and Xylene values within each group mentioned above. These values were then plotted and compared with Tier 1 Remediation Objectives to understand the extent and exceedance of each contaminant under study.

**Table 4: Remediation objectives and actual maximum concentration of BTEX compounds as found in shallow surface soils (0-3 ft bgs) at the site.**

| **Contaminant** | **Remediation Objective** *(micrograms per kilogram)* | **Actual maximum concentration** *(micrograms per kilogram)* |
|---|---|---|
| Benzene | 30 | 14,500 |
| Ethyl benzene | 13,000 | 74,000 |
| Toluene | 12,000 | 0 |
| Xylene | 5,600 | 91,700 |

Table 3 shows that out of a total of 28 samples tested, Benzene was reported in all 28 samples and ranged from 0.7 µg/ kg to 14,500µg/kg. Ethyl benzene was reported above detection limits for 25 samples and ranged from 1.1 µg/kg to 74,000 µg/kg. Toluene was not reported in shallow surface soils for any sample. Total Xylene was reported in 27 samples ranging from1.8 µg/kg to 91,700 µg/kg.

**Table 5: Remediation objectives and actual maximum concentration of BTEX compounds as found in shallow subsurface soil (3-10 ft bgs) at the site.**

| **Contaminant** | **Remediation Objective** *(micrograms per kilogram)* | **Actual maximum concentration** *(micrograms per kilogram)* |
|---|---|---|
| Benzene | 30 | 56,000 |
| Ethylbenzene | 13,000 | 145,000 |
| Toluene | 12,000 | 54,000 |
| Xylene | 5,600 | 140,000 |

Table 4 shows that all four compounds are found in concentrations above the remediation objectives at 3-10 feet depth of soil surface. Out of a total of 30 samples tested, Benzene was reported above detection limits for 27 samples and ranged from 0.7 μg/kg to 56,000 μg/kg. Ethyl benzene was reported above detection limits for 27 samples and ranged from 0.8 μg/kg to 145,000 μg/kg. Toluene was reported in 24 samples ranging from 1.0 μg/kg to 54,000μg/kg. Xylene was reported in 29 samples ranging from 1.0 μg/kg to 140,000 μg/kg.

**Table 6: Remediation objectives and actual maximum concentration of BTEX compounds as found in deep subsurface soil (beyond 10 bgs) at the site.**

| **Contaminant** | **Remediation Objective** *(micrograms per kilogram)* | **Actual maximum concentration** *(micrograms per kilogram)* |
|---|---|---|
| Benzene | 30 | 659,000 |
| Ethylbenzene | 13000 | 797,000 |
| Toluene | 12000 | 1,540,000 |
| Xylene | 5600 | 1,300,000 |

Table 5 shows that at 3-10 feet depth of soil surface, out of a total of 59 samples tested, Benzene was reported above detection limits for all 59 samples and ranged from 0.7 μg/kg to 659,000 μg/kg. Ethyl benzene was reported above detection limits for 45 samples and ranged from 0.8 μg/kg to 797, 000 μg/kg. Toluene was reported in 58 samples ranging from 1.0 μg/kg to 1,540,000μg/kg. Xylene was reported in 57 samples ranging from 1.0 μg/kg to 1,300,000μg/kg. This indicates very high concentrations of Benzene, Ethyl Benzene, Toluene and Xylene at greater depths indicating that pollutants have migrated to deep soil depths. The following graphs give an idea of the extent of exceedance of remediation objectives by these BTEX compounds.

Contaminants (Fig. 12) are shown on the X axis; Y axis shows concentration of these compounds at different depths. All three graphs show BTEX compounds exceeding the remediation objectives (except for **toluene** which is absent at 0-3'feet on the site). An interesting observation here is that the graphs show concentration of these compounds are greatest at a depth beyond 10' than. This indicates that not much is found at surface because compounds have migrated vertically in plugs.

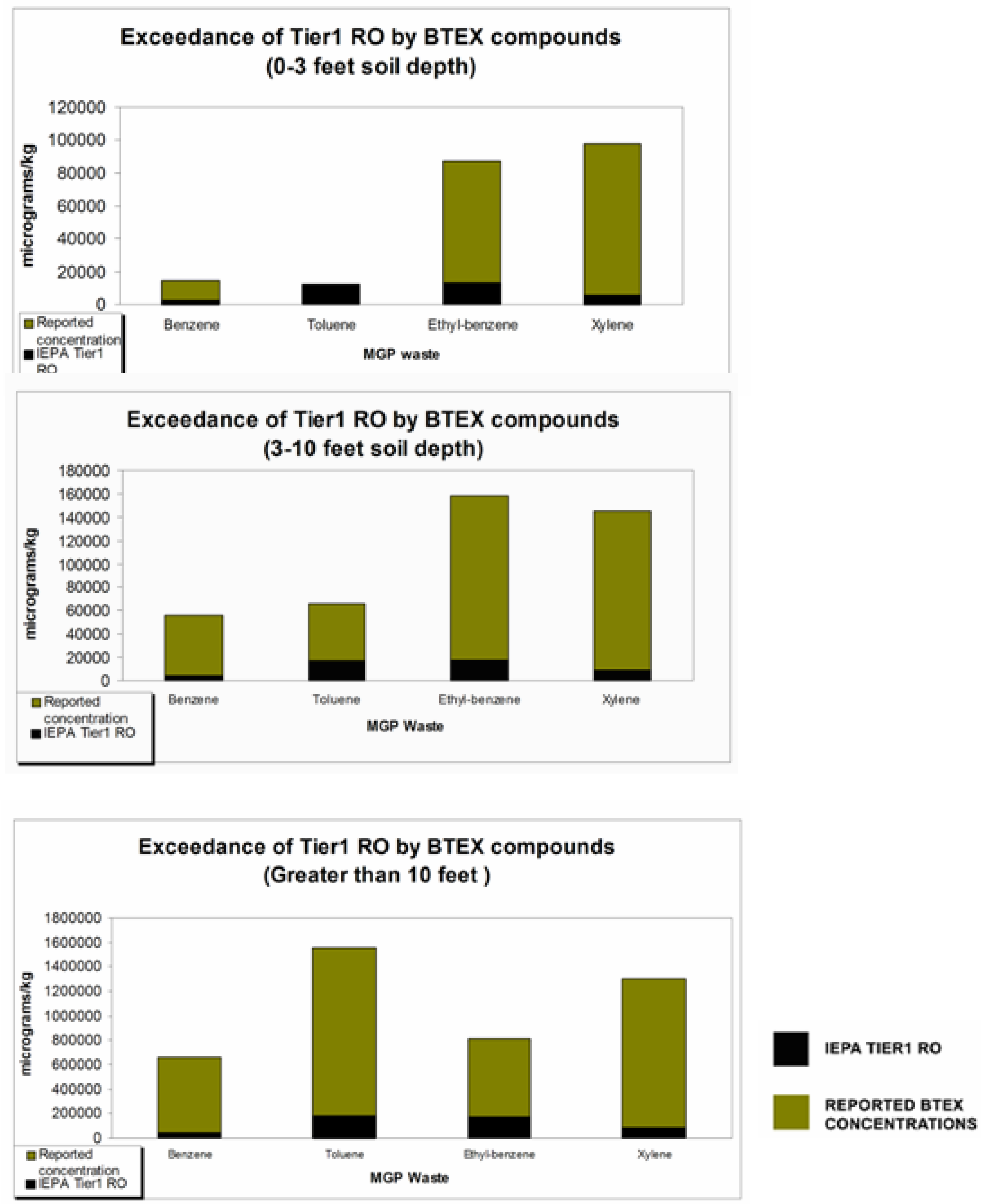



**Figure 12: Exceedance of Remediation Objectives by BTEX compounds as specified by EPA.**

Contaminants are plotted on X axis, Y axis shows concentration of these contaminants at different depths in micrograms/ kg. All three graphs indicate that BTEX compounds are exceeding the remediation objectives except for **toluene** at 0-3' depth. Graphs also show that concentration of these compounds is more at a depth beyond 10' than the other two levels.

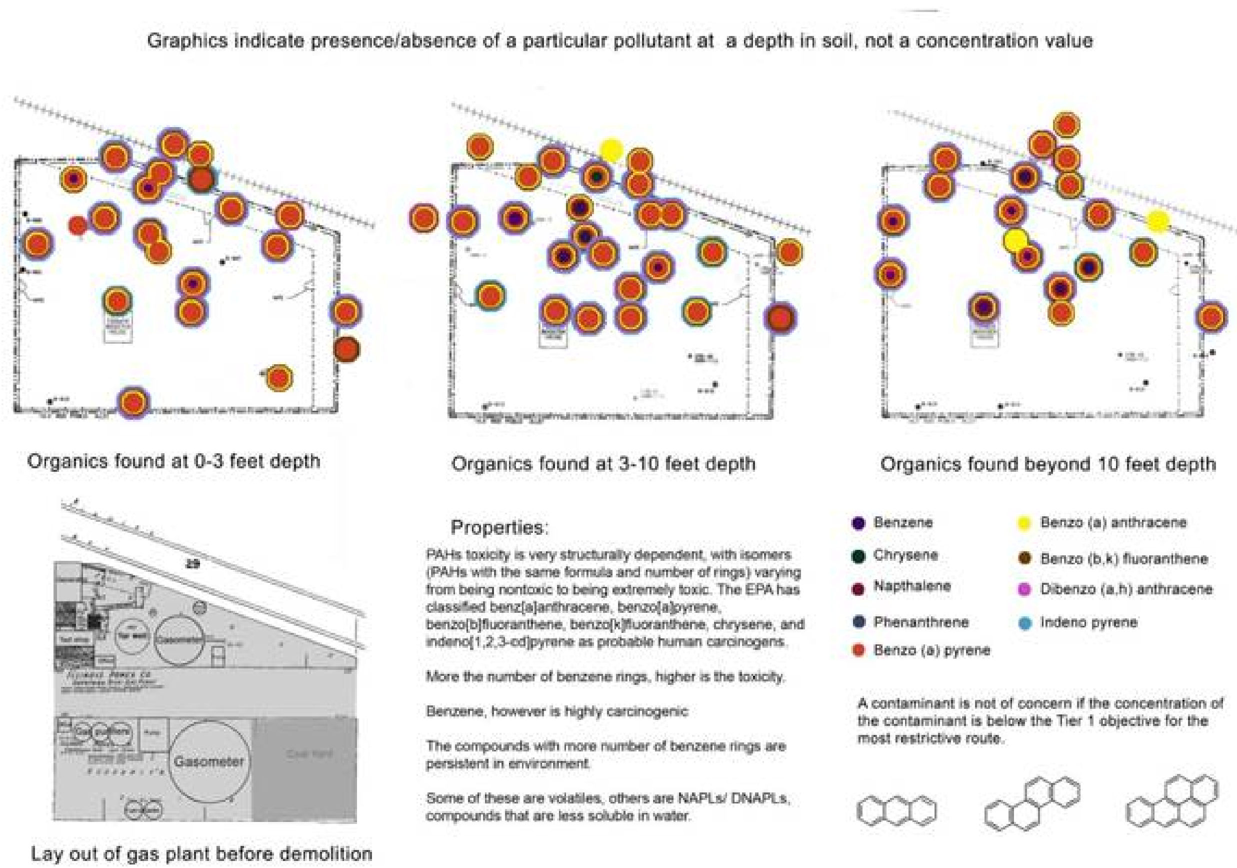



**Figure 13: Mapping Contaminants exceeding Remediation Objectives as specified by EPA.** Polyaromatic hydrocarbons exceeding remediation objectives are mapped in the above figure. After comparing contamination at each depth (surface, shallow subsurface and deep subsurface) with the map layout before demolition, it is observed that the tar well and a gasometers were in the same area of the site where most contamination is observed. This explains the occurrence of major contamination in the area where these structures existed (Image adapted from: Base maps- Philip Services Corporation, 2007).

Polyaromatic hydrocarbons exceeding remediation objectives are mapped in Fig. 13. They follow a similar pattern as far as their migration in soil. They have moved in plug flow and it's seen from the diagram that they are concentrated at 3-10 feet and have also migrated in deep soil. If these diagrams are compared with the map layout before demolition, it is observed that the tar well and a gasometers were in the same area where the greatest contamination is observed.  Tar wells and gasometers were always known to leach coal tar and tar based compounds into soil and in the diagram, the presence of contaminant hot spots in those areas suggests that they are the most probable sources of contamination on site.

In conclusion, this data gives a clear idea of qualitative and quantitative information about contaminants of concern. This information forms the basis for choosing remediation technologies that address deep soil and ground water contamination.

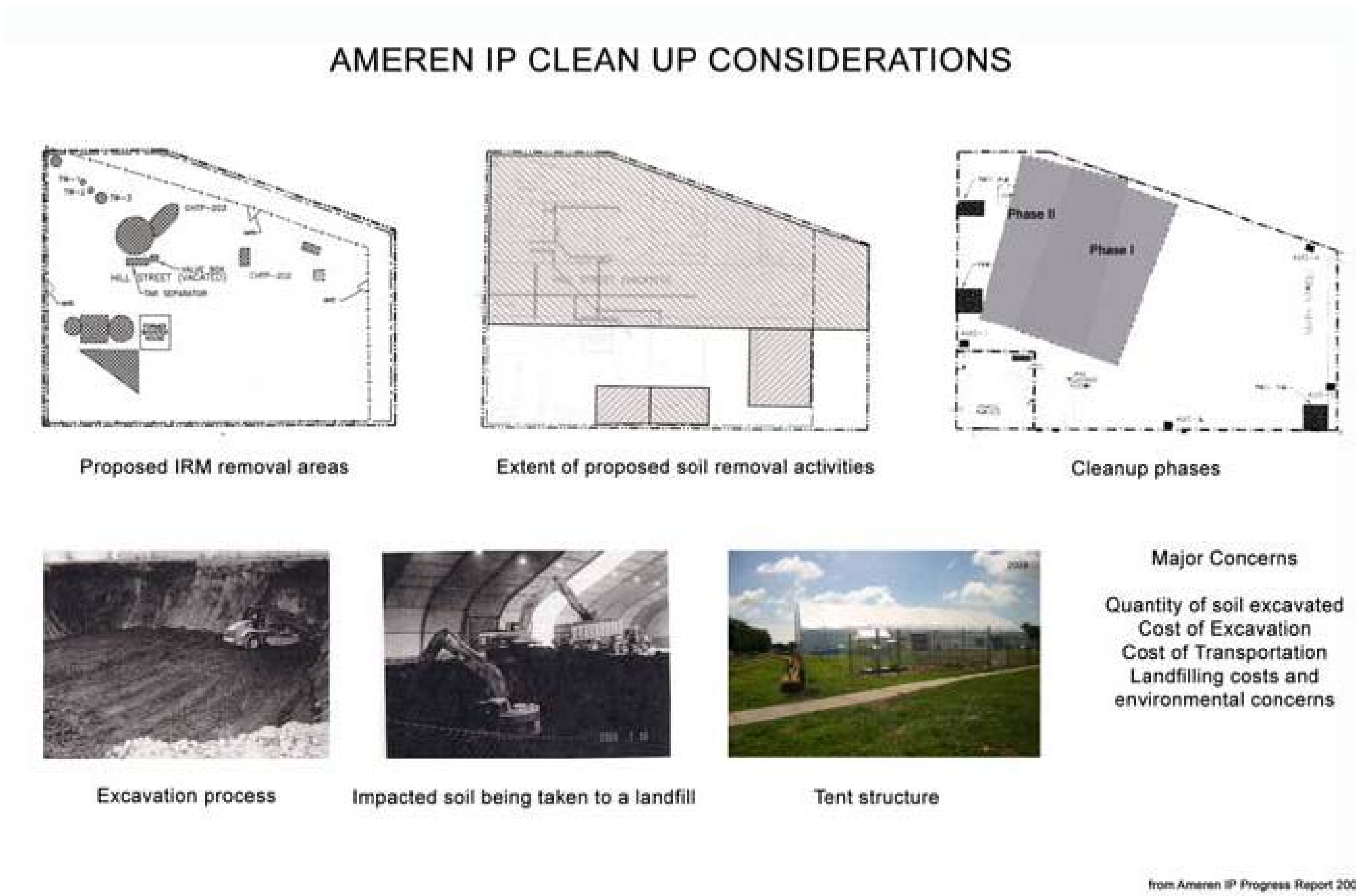



**Figure 14: Showing excavation plan and activities for the FMGP at Champaign, IL by Ameren IP.** Ameren IP is removing up to 28' of soil mostly from the northern part of the site where maximum contamination is observed and also from some southern portions of the site. The excavation is being carried out in phases and the figure above is showing proposed soil removal area, schematic diagram for clean up in phases and actual photos of the tent structure, actual, process of excavation and impacted soil being taken to a landfill (Image source: Philip Services Corporation, 2007).

## AMEREN IP CLEANUP-CONSIDERATIONS

According to Champaign, IL Manufactured Gas Plant site progress report (2009), Ameren IP has been excavating up to 28' feet of soil in phases from mid 2009. Workers have found impacts as deep as 28' and would remove the entire layer of soil offsite and to a landfill, to greatly remove contamination and eliminate the amount of follow up treatment that will be required when the excavation is complete. A tent structure has been placed over the area being excavated and will be moved to other parts of the site in phases during clean up. After the impacted soil for a phase is removed, clean soil from an offsite source is being brought to the site to be placed in the excavated area (Fig. 14). The excavation will then be backfilled, compacted and regraded to the original ground surface. Methods to address deep soil impacts that cannot feasibly be removed with excavation equipment were investigated prior to starting cleanup activities. A pilot study for *in situ* chemical oxidation has been done during the first clean up phase. They propose to use this treatment method for some soil impacts in certain on site and off site areas.

Excavation is a commonly used to remove contaminated soil. It is easy to perform, and it rapidly removes the contamination from the site, as opposed to remediation methods, which may require several months. But there are problems associated with this activity as it allows release of contaminant vapors to the ambient air. In addition, excavated soil must be transported to a place where it is treated or land filled both of which generate transportation costs. Also, land filling is not a good option because the problem of contamination is not solved but just transferred to the landfill, thereby increasing its toxicity. Excavated area must also be filled with clean soil and this would require excavation and transportation of clean soil thereby disturbing the natural soil processes on other sites and increasing the costs of the overall project. Excavation also increases the possibility of contaminants leaching into the environment and exposure to workers handling the contaminated soil (Riser-Roberts, 1998).

In conclusion, excavation may not be the most effective way of removing contamination. It is a very expensive and unsustainable practice and the major concerns associated with excavation are cost related to man hours, power equipment required to excavate the soil, transportation of soil to a landfill, cost of land filling and backfilling of soil on site. However, the most important cost that needs attention here is the environmental cost. When the hazardous material is transported to a landfill, it does not solve the problem but just transports it making another place more toxic and deleterious to both health of people and the environment.

# Chapter 6: Remediation Technologies

## Part I

### Overview of Remediation Technologies

Soil treatment technologies are often developed and evaluated to conform to regulatory demands which may, for example require or suggest that residual total petroleum hydrocarbon concentrations in soil be reduced below the remediation objective. There are many technologies available for treating sites contaminated with petroleum hydrocarbons or coal gas contaminants specifically; however the treatment selected depends upon contaminant and individual site characteristics, regulatory requirements, costs and time constraints (Riser – Roberts, 1998).

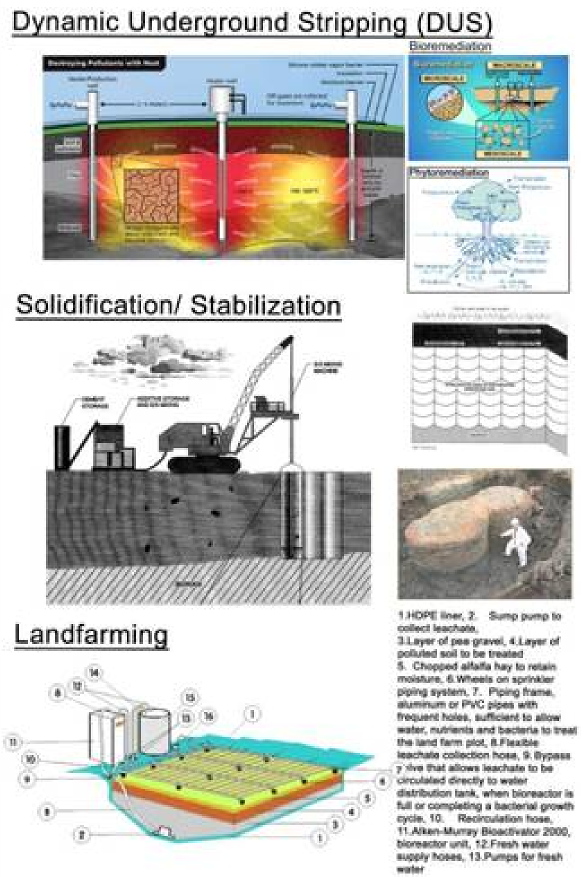
The study mapping the extent of contamination identifies the need to address deep soil and ground water contamination. Cutting edge technologies were screened for this purpose and three *In situ* treatment technologies most effective for removing MGP wastes reaching a depth of 30’ were selected. Fig. 15 gives a list of technologies that were studied to further screen technologies for effective remediation of MGP contaminated soil. The list includes Capping, Chemical Oxidation, Dynamic Underground, Stripping, Dual Phase Extraction, Solidification/ Stabilization, Steam Extraction, Bioremediation, Biosparging, Phytoremediation, Soil Vapor Extraction and Landfarming. Further, Fig. 15 presents a summary of technologies, costs, benefits and limitations for technologies chosen for remediating MGP wastes to address deep soil contamination, as per the EPA publication "A resource for MGP site characterization and remediation”. Further benefits, limitations, and costs of each technology, by way of case studies and examples, are discussed.

**Table 7: Overview of Remediation Technologies for removal of MGP contaminants (EPA, 2000).**

| Sr. No. | Technology | Description |
|---|---|---|
| 1. | Capping and Containment | Used to significantly reduce contaminant migration to prevent human and animal exposure. |
| 2. | Excavation, Transportation, Landfilling | Contaminated soil is excavated and hauled to a landfill. |
| 3. | Dynamic Underground Stripping | High temperatures produced by the heating electrodes burn most pollutants out of the soil. Others are volatilized along with any moisture present in the soil. Gases formed in process are sucked toward the vacuum wells and treated completely. |
| 4. | Dual Phase Extraction | Uses high-vacuum system to remove soil vapor |
| 5. | Solidification/ Stabilization | Mixing of contaminated soils with Portland cement + additives, lowers soil hydraulic conductivity, encapsulates soil and blends contaminants uniformly. A solidified monolith is formed that immobilizes contaminants completely to avoid outside contact. |
| 6. | Steam Extraction | Injection wells force the steam into the ground, where it displaces or volatilizes pollutants, pushing them toward an extraction well. |
| 7. | Bioremediation | Processes that use bacteria, fungi and algae to break down contaminants into less toxic- nontoxic compounds like carbon dioxide and water. Can be enhanced by bioventing. (providing oxygen to soils) |
| 8. | Biosparging | Air and nutrients are injected into the soil below the water table. Organisms already in the soil are used to degrade contaminants. Sometimes bacteria that have been selected for breaking these compounds specifically are added. Used with Soil Vapor Extraction technique. |
| 9. | Phytoremediation | Removal of organics from soil by uptake and degradation, rhizodegradation or phytoextraction and phytovolatilization. |
| 10. | Soil Vapor Extraction | Extraction of air from subsurface to remove volatile compounds from vadose zone soils. |
| 11. | Landfarming | Destruction of organic compounds in soils by microorganisms. Treatment occurs on lined beds during contaminated soil tilling |

PHYSICAL CHEMICAL BIOLOGICAL

# PROPOSED IN SITU REMEDIATION TECHNIQUES




| | TECHNOLOGY | DURATION& COSTS | ADVANTAGES & LIMITATIONS |
|---|---|---|---|
| 1. | Dynamic Underground Stripping (DUS) (electric heating system to volatilize and mobilize organic contaminants) | Few months to an year<br>$ 110/ cubic yard Equipments Installation | - Range of soil types<br>- Saturated and unsaturated conditions<br>- Possible in areas where traditional excavation mpossible<br>- Deeper depths |
| 2. | Solidifaction/ Stabilization (encapsulation with chemical binders to immobilize organic contaminants) | Few months<br>$ 40-60 / cubic yard in shallow applications | - Neutralizes soil<br>- Improves bearing capacity or shear strength of the area.<br>- Possible leaching of mobile contaminants.<br>- Creation of concrete like material in subsurface. |
| 3. | Landfarming Destruction of organics in subsurface by microorganisms on lined beds | Few months<br>$ 75 / cubic yard exclusive of lab and pilot studies. | - Generally inexpensive<br>- Very effective for PAHs and organics in general<br>- Shorter treatment periods than in situ bioremediation alternatives<br>- Slower treatment , pilot studies |
| 4. | Bioremediation Destruction of organics in subsurface by microorganisms | Few months to a couple of years<br>$ 10-$ 70/ cubic yard exclusive of lab and pilot studies | - Generally inexpensive<br>- Very effective for PAHs and organics in general<br>- Slower treatment<br>- Needs pilot studies |
| 5. | Phytoremediation Used in a treatment train with other technologies | Long term (years)<br>$ 4/ cubic yards if same equipment and materials common to agricultural practices used OR $ 17/ cubic yard | - Provides in situ treatment (train)<br>- Serves as interim solution<br>- Permanent solution for removing organics, cheap<br>- Incorporated in to designs<br>- Slow treatment<br>- Needs pilot studies |

**Figure 15: Remediation technologies – Costs, Advantages and Limitations.** Figure shows remediation technologies that were chosen to address deep soil contamination and a comparison of their costs, advantages and limitations (Image source: Montage of images, all taken from Google Images).

**Part II**

**Discussion of selected technologies with case studies**

**1) Dynamic Underground Stripping:**

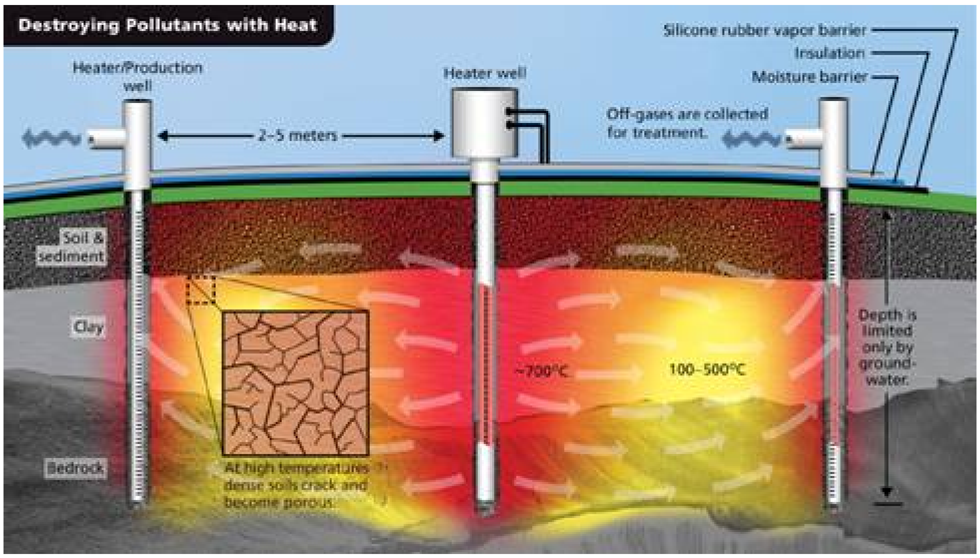



**Figure 16: Dynamic Underground Stripping.** Dynamic Underground Stripping is used to volatilize contaminants and destroy them in place. The system consists of a central heater well that is surrounded by six wells that contain heating and vacuum mechanisms. The high temperatures produced by the heating system burn most pollutants out of the soil. Electrical heating may be applied to less-permeable contaminated clay layers to help release contaminants from the soil making this technology suitable for site under study (Black, 2002).

<u>Process:</u>

Dynamic Underground Stripping is a kind of i*n situ* thermal destruction technique in which ground is heated using electricity and contaminants are volatilized to remove from the ground or destroyed in place. The soil is heated to boiling point of water using electrically powered heating electrodes. If contaminants are burnt in absence of oxygen, only carbon is left and in presence of oxygen, carbon dioxide and water are left. The elements are contained inside pipes that are normally spaced 5–7 feet apart for a cleanup that will take 1–3 months. For treating heavy contaminants with higher boiling points, such as heavy oils, the spacing would be closer.

The system consists of a central heater well that is surrounded by six wells that contain heating and vacuum mechanisms. The high temperatures produced by the heating system burn most pollutants out of the soil. The remaining pollutants are volatilized along with any moisture present in the soil. All the gases that result from this process are sucked toward the vacuum wells, where they are collected and treated. Even heating is important because it ensures there will be no untreated spots. DUS generally does not require material handling or pretreatment prior to application at a site. Electrical heating may be applied to less-permeable contaminated clay layers to help release contaminants from the soil and hence this technology could be appropriate for this site. DUS requires both subsurface and aboveground equipment. Aboveground equipment includes a steam generation plant, electrical heating equipment, and treatment systems for recovering free product and contaminants from the separate liquid and vapor streams collected from the extraction wells. So the components that are released through the extraction wells are safely collected in treatment systems and not allowed to come in contact with land or air again. The DUS treatment system consumes significant quantities of electricity and water (Black, 2002).

<u>Case study:</u>

In 1997–1998, Shell used this technology to treat several sites contaminated with contaminants like polychlorinated biphenyls, chlorinated solvents, and diesel and gasoline. After the treatment soil samples were tested for trace contaminants and the post-treatment confirmatory soil samples had just a few minimal traces. Terra Therm's, a world wide leader in the development of thermal technologies have cleaned up 5,000-cubic-yard site in Lake Charles, Louisiana. The site is owned by Entergy Gulf States, and is a former manufactured gas plant highly contaminated with tar.

This method successfully cleaned up soil contaminated with the solvents trichloroethane and trichloroethylene at an electronics manufacturing facility in Skokie, Illinois (EPA, 1999). The process ran from June 1998 through April 1999. The Six Phase Heating System used at the Skokie, Illinois site achieved the established Tier III cleanup goals for the remediation of the initial estimated 23,000 cubic yards of contamination at the site in about six months and for the remediation of the additional 11,500 cubic yards of contamination at the site in about five months. In addition, the concentrations of constituents in a number of wells had been reduced to the more stringent Tier 1 standards. (EPA, 2000)

Dynamic Underground Stripping averages $110 per cubic yard. Although the initial capital outlay for DUS is higher than for pump-and-treat systems, DUS could save money in the long run because it is completed much more quickly. Initial expenditures include installing the heating wells and operating the system intensively for a short period of time (EPA, 2000).

Benefits:

1) The technology works in a wide range of soil types in both saturated and unsaturated soil conditions.

2) Treatment is possible in areas where traditional excavation and removal are impossible.

3) Minimal disruption to nearby industrial operations or surrounding neighborhoods; no digging and hauling of contaminated materials eliminates exposure to toxic fumes and dust Will work close to or under existing structures, including buildings and roadways (EPA, 2000).

Limitations:

1) Operation difficulties that may be encountered during DUS include scaling and deposits on sensors, clogging from fines brought to the surface, and difficulties in maintaining the cycling, pressure varying, and high-temperature.

2) Further refinement is also required for system design and operating and monitoring techniques.

3) The DUS technology is labor intensive, requiring significant field expertise to implement.

4) It is also one of the most expensive technologies available for remediation of organic compounds (EPA, 2000).

## 2) *In situ* stabilization / solidification

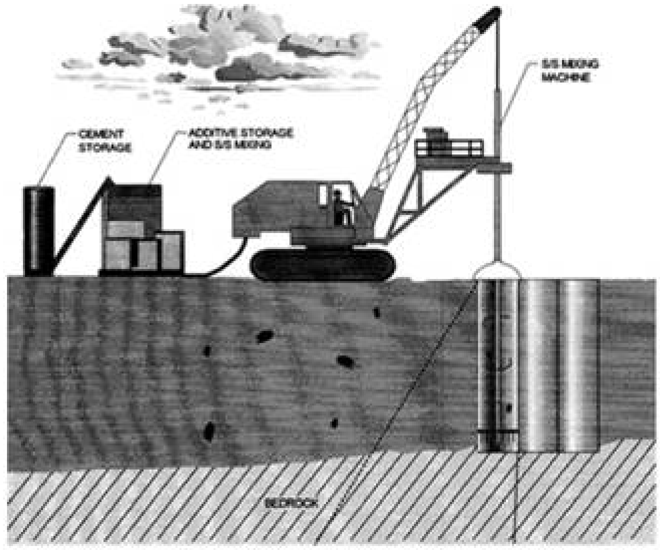



**Figure17: *In situ* stabilization / solidification.** *In situ* stabilization is used to immobilize contaminants by mixing the soil with Portland cement and other additives. Equipment required for the process is cement storage tank, cranes, and mixing machines. In-place columns are constructed, and soils and residues are treated *in situ* to depths of 30 feet making this technology suitable for site under study (EPA, 2000).

Process:

*In situ* solidification/stabilization (S/S) is a remediation technology that can be used successfully for MGP-related soil contamination. In-place columns are constructed, and soils and residues are treated *in situ* to depths of 30 feet or more. *In situ* S/S involves mixing soil with chemical binders such as cement, bentonite, additives, and proprietary chemicals to immobilize contaminants of concern (e.g., PAHs). A crane-mounted drill attachment turns a single-shaft, large diameter auger head consisting of two or more cutting edges and mixing blades. As the auger head is advanced into the soil, grout is pumped through a hollow drill shaft and injected into the soil. The cutting edges and mixing blades blend the soil and grout with a shearing motion. When the design depth is reached, the auger head is raised to expose the mixing blade at the surface and then advanced again to the bottom. Once the shaft is completed, another column is drilled using a specified pattern of overlapping columns; what is left behind is a series of interlinked columns (EPA, 2000).

The success of S/S methods is based on the type of soil and its properties, the type of contaminants and their concentrations, moisture and organic content, density, permeability, leachability, and pH. A treatability study is recommended for this technology to create a mix that minimizes leaching and has appropriate strength characteristics. The creation of concrete-like material in the subsurface may severely limit access to utilities, which may need to be permanently rerouted. The machinery used for *in situ* S/S via mixing augers is approximately the same size as a large drilling rig (EPA, 2000).

<u>Case study:</u>

The Wisconsin Fuel & Light site, located along the Manitowoc River in Wisconsin, had been filled with construction and other debris. Parts of the foundations from the previous coal gasification structures were also present on site. The soils on site were contaminated with coal tars and were stabilized using a reagent mixture of fly ash, activated carbon, and cement. Impacted soil was stabilized by simultaneous injection and mixing of cement-based grout and a series of overlapping columns of stabilized soil were created. Approximately 15,000 cubic yards of soil were treated during a 2-year period to an average depth of 32 feet. Of 16 extracts, only one contained a PAH (naphthalene at a concentration of 16 μg/L), and no other SVOCs were detected above the Minimum Detection Limit (EPA, 2000).

Costs for cement-based S/S techniques vary widely according to materials or reagents used and their availability, project size, and the chemical nature of the contaminants. *In situ* mixing/auger techniques average $40 to $60 per cubic yard in shallow applications.

<u>Benefits:</u>

1. Neutralizes soil and immobilizes contaminants.
2. Leaves treated area, if reinforced, able to withstand differential soil and hydrostatic loading.

<u>Limitations:</u>

1. Possible leaching of volatile or mobile constituents.
2. Creation of concrete-like material in the subsurface (may severely limit access to utilities, which may need to be permanently rerouted).

3. Possible significant increase in volume of mixture (up to double the original volume).
4. Reagent delivery and effective mixing more difficult than in ex situ applications.
5. Low overhead lines may limit the use of this technology.

**3) Landfarming:**

**Figure 18** (Left)**: Tilling operations are used to aerate the contaminated soil.**
**Figure 19** (Right)**: Contaminated soil is excavated and placed onto prepared beds** (Image source: Google Images).

Process:

Landfarming (also called land treatment) involves aerating contaminated soil by excavating it and placing it on lined beds. Tilling is required to periodically aerate the soil. It is first irrigated and then treated with nutrients optimize growing conditions for bacteria that would degrade contaminants from the soil. Soil is placed onto prepared beds or liners to control leaching of contaminants and is treated in lifts that are up to 18 inches thick. After the desired treatment is achieved, the lift is removed and a new lift is constructed. It is advantageous to use the remediated lift to prepare a new lift as this strategy inoculates freshly added material with an actively degrading microbial culture and can reduce treatment times (EPA, 1999). Soil conditions are controlled for bioremediation to optimize the rate of contaminant degradation. Conditions typically controlled include are moisture content, aeration, pH, nutrients and other amendments. Most importantly, to determine whether bioremediation is an appropriate and effective remedial treatment for the contaminated soil at a particular site, it is necessary to characterize the contamination, soil, and site, and to evaluate the biodegradation potential of the contaminants. A preliminary treatability study for the landfarming bioremediation should identify: amendment mixtures that best promote microbial activity, percent reduction and lowest achievable concentration limit of contaminant, and potential degradation rate (EPA, 1999).

Bioremediation methods have been used to treat petroleum hydrocarbons, VOCs, and PAHs. As a rule of thumb, the higher the molecular weight (and the more rings a PAH has), the slower the degradation rate. Landfarming is very simple from a technology point of view and the costs for treatment include approximately \$75 per cubic yard for the prepared bed. Studies conducted prior to treatment can range from \$25,000 to \$50,000 for laboratory studies, and \$100,000 to \$500,000 for pilot tests or field demonstrations (EPA, 1999).

<u>Case study:</u>

MidAmerican Energy used landfarming as a remediation technology for clean up of a MGP site in Des Moines, Iowa. Two complementary remedial techniques of chemical oxidation and biological treatment were used for remediation process. Fenton's reagent was used to produce hydroxyl radicals that start a chain reaction with the organic contaminants. With this chain reaction, organic compounds specifically polyaromatic hydrocarbons were transformed into products that are more readily degraded by microorganisms. The Vandalia Road site is a former landfill that contains residues from a former MGP related to the Capital Gas Light Company site located in Des Moines. The Vandalia Road MGP site is located in a rural area, even though it is within the city limits of the City of Pleasant Hill and is surrounded by company-owned farmland that was used to construct an adjacent treatment facility (EPA, 2000).

The treatment area of the facility was around 30,000 square feet, and was lined with high-density polyethylene (HDPE). The two 12-inch lifts each had a capacity of 1,000 cubic yards. An additional facility was built adjacent to the site and included a water retention basin, an automatic sprinkler system, a decontamination/soil processing pad and a field laboratory. Soil and other material were spread across the facility using a bull dozer to a consistent depth of 12 inches. The routine operations for the biological portion of the process consisted of aeration of the soil, addition of nutrients, and maintenance of the proper moisture content. Standard agricultural equipment such as field cultivators, rototillers, and a two-bottom plow were used. A critical parameter for biological degradation is the moisture content of the media treated; moisture content needs to be between 40 and 80 percent of field-holding capacity. During the first year of operation of the biological treatment phase, total PAH reduction was 51 percent. Chemical treatment reduced total PAHs by an additional 20 percent, and degradation of 4- to 6-ring compounds was increased twofold (EPA, 2000).

Benefits:

1. Does not need advanced treatment equipment.
2. Cheaper compared to other high end technologies.
3. Very effective for PAHs.

Limitations:

Landfarming requires a large amount of space and is dependent on environmental conditions affecting biological degradation of contaminants (e.g., temperature and rainfall). VOC emissions and dust control are also important considerations, especially during tilling and other material handling operations.

**Phytoremediation:**

Phytoremediation is a process of degradation of contaminants using plants. The phytoremediation technology is used independently but is also used to assist in scavenging remaining contamination after application of a primary treatment technique has been used on the site and is called as 'treatment train' technology. Phytoremediation of hydrocarbons in soil involves plants and their associated microorganisms as well. Plants harbor microorganisms in their roots which form a symbiotic relationship with them and assist in break down of complex contaminants in the soil. A general category of plants that are known to grow in hydrocarbon –contaminated soil are native forbs, legumes, grasses and naturalized legumes and grasses (Robson et. al, 2003). Plants with a demonstrated potential to remove petroleum hydrocarbons are shown in Fig.19. Table 7 lists a range of microorganisms that are capable of degrading specific hydrocarbons.


**Figure 20: Plants effective in removing coal tar wastes and petroleum hydrocarbons.** These are plants are known to be used effectively for phytoremediation (Image source: Montage of images, all taken from Google Images.).

**Table 8: Genera of hydrocarbon degrading microorganisms and specific contaminant application.**

| Microorganism | Contaminant |
|---|---|
| **Bacteria:** | |
| *Acidovorax spp.* | Phenanthrene, anthracene |
| *Arthrobacter spp.* | Benzene, naphthalene, phenanthrene |
| *Pseudomonas spp.* | Phenanthrene, fluoranthene, benzo(a) pyrene |
| *Sphingomonas spp.* | Phenanthrene, fluoroanthene, anthracene |
| *Alcaligenes spp.* | Phenanthrene, anthracene |
| *Mycobacterium spp.* | Phenanthrene, pyrene, benzo (a) pyrene |
| *Rhodococcus spp.* | Pyrene, benzo (a) pyrene |
| **Fungi:** | |
| *Cunninghamella spp.* | Benzo (a) pyrene |
| *Penicillium spp.* | Benzene, naphthalene, phenanthrene |

# Chapter 7: Cost Analysis

Using a rough estimate of the costs associated with each technology some basic level cost analysis for each of the technologies was performed. Cost analysis was further used to compare cost of each technology used. 'Excavation, transportation and land filling' is commonly thought of as the fastest and best way to remove material from a toxic site. However the thesis argues that, even though associated costs are lesser and the removal of contaminants is comparatively faster, excavation and landfilling transports a problem from one place to another without solving it. Table 8 gives the potential cost analysis of each method considered for cleaning up the former MGP site in Champaign, IL.

**Table 9: Cost Analysis for treatment technologies (EPA, 2000).**

| Sr. No. | Treatment Alternatives | Project costs for 2.5 acre |
|---|---|---|
| I. | Capping and containment | **$ 112,500 to $ 425,000** |
| II. | Landfilling | **$ 6.671 million** |
| | Excavation, Transportation | $ 371,000 |
| | Disposal | $ 6.3 million |
| III. | Dynamic Underground Stripping | **$ 9.9 million** |
| IV. | Stabilization/ Solidification | **$ 4.5 million** |
| V. | *In situ* Landfarming | **$ 9.4 million** |
| | Excavation, Tilling and other practices | $ 6.7 million |
| | Bioremediation | $ 2.7 million |
| VI. | *In situ* Landfarming | **$ 7.05 million** |
| | Excavation, Tilling and other practices | $ 6.7 million |
| | Phytoremediation | $ 0.35 million |

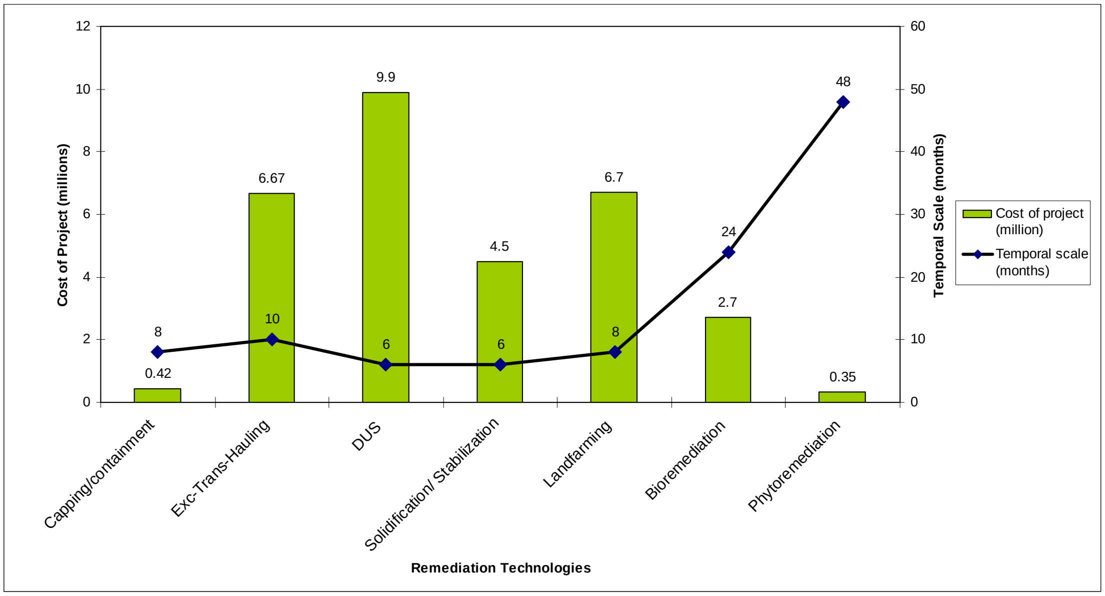



**Figure 21: Graph comparing temporal scale and costs of projects under study.** Remediation technologies are compared for their overall effectiveness using cost of the project and time required for each technology to complete. The graph shows that the most cost effective among techniques is stabilization/solidification but DUS is the fastest technology.

Choosing an appropriate technology for a site involves many variables for successful remediation among which remediation costs and time required for clean up are extremely important. Capping and containment ($425,000) requires rigid institutional controls to ensure that the site is not planned for redevelopment in the future. Moreover, it does not clean up the site and continues to pose unknown threats to public health. However, if it is compared with phytoremediation which in spite of its similar costs may not be a viable solution for this site as it will not address the deep soil contamination due to the limitation of the extent to which roots of plants can reach below ground. Excavation – transportation- hauling (6.67 millions) removes toxicity from the site but transports the problem, and so is an unsustainable solution. Landfarming on the other hand costs about the same and is a better solution. Dynamic Underground Stripping is the most expensive technology however; it is the fastest and the most effective of all, in that it completely removes the toxicity from the site. Bioremediation cannot be used independently on the site but could work in a treatment train type remediation with landfarming and dynamic underground stripping technology which uses different strains of bacteria to clean up residual contamination. Among all the technologies studied for use at the gas plant, *In* *situ* stabilization has a potential to offer the best solution. It takes around 6-8 months to complete the remediation process and costs $ 4.5 million, which as seen from the graph in figure 21 is not the cheapest solution but still the best one if the costs, time taken and effectiveness of this technology are compared with other technologies.

# Chapter 8: Discussion

**Speculative Projections:**

Brownfields are cleaned up to comply with regulatory standards but are transformed to leave no trace of their past. Regeneration of contaminated urban land often wipes out the history of the site. This thesis argues that landscapes should be reclaimed in a way that honors people that made them. Their activities were certainly unsustainable but the underlying intentions were not necessarily bad. It is very important to note here the fact that coal gas and the manufactured gas plants that produced it were in huge demand in 1800s. They were one of the important drivers of industrial revolution in U.S as well as in other parts of the world. We can easily draw parallels between manufactured gas plants then and nuclear power plants that exist today. It is almost impossible to understand in entirety, the social and environmental implications that nuclear energy will bring with it a hundred years from now. A timely and even more recent comparison may be the human desire for oil and its undesirable discharge into the ocean a mile below the surface following the explosion of the Deep Water Horizons oil rig in the Gulf of Mexico (April 22, 2010). The oil leak is said to be one of the largest man made disasters in the Gulf of Mexico with unintentional environmental effects similar to past but perhaps even more extreme with irreplaceable ecological damage.

The urgent effort to clean and reclaim "blasted" landscapes often involves an unfortunate exercise of cultural and historical amnesia. If former buildings and landscapes on contaminated sites were interpreted for the public, we would retain an important material framework for better understanding of the sites. Also, with tangible traces of former uses left in place, we would have an important venue for learning about the human use, abuse, and stewardship of the built and natural landscape. Landscapes when stripped of their identity, and adapted to new reuse make less sense to residents and visitors alike (Bluestone, 2007).

Some people with an understanding of these polluted sites might feel that the less said, the less shown, over time, the better. However, such ignorance about the past is unnatural and ultimately undercuts the very work we are trying to accomplish in the remediation of polluted sites. As a solution, stakeholders could make their efforts more comprehensible and decidedly less scary to the public if they could reveal how the flows of materials and pollutants on toxic sites had actually taken place. To see toxic sites as part of a broader industrial process with material inputs, products, and by-products that all worked their way through the buildings and the site would promote a more critical understanding of basic site processes that could increase understanding about the processes of site pollution, site remediation, and site reuse (Bluestone, 2007).

Along with concealing history of the sites, it is common practice to cover up remediation processes as well. This thesis argues that a paradigm shift is definitely warranted in this case as recently developed sophisticated technologies offer a great opportunity to understand remediation processes that bring about revival of polluted sites. We live in a post industrial landscape and it is time for us as a society to embrace the reality and inevitability of toxic landscapes in a city. The thesis, thus aims to understand and determine ways we can reclaim the site, remember the past and reveal infrastructural processes customarily hidden during remediation processes.

**I. Dynamic Underground Stripping:**

I used Grand Prismatic Spring, a hot spring in Yellow Stone National Park as precedence for revealing the DUS remediation technology. The spring is an enormous and colorful example of thriving thermophilic bacteria. Different species of bacteria occupy different areas of the spring and produce a variety of vivid colors as a result of species specific pigmentation. Based on this natural phenomenon, I propose that a part of the immense heat produced below ground for DUS be harnessed to grow similar kinds of thermophiles to produce a thermal pond. These bacteria perform a dual role. They provide aesthetic interest in the form of vibrant colors and also clean up the soil. This design would however be functional only while the remediation processes are at work. Later, the site could be transformed to support any land use or if desired more research could be conducted to continue the thermal pond demonstration.

**Figure 22: Design Precedence - Grand Prismatic Spring, Yellow Stone National Park, Wyoming, U.S.** The spring is used as precedence for revealing the DUS remediation technology to public. Heat produced below ground for DUS shall be harnessed to produce a thermal pond like this Grand Prismatic Spring. Different species of thermophilic bacteria in the spring could provide clues to cultivate similar kind of bacteria in the thermal pond on the site using laboratory research. Thermophilic bacteria perform a dual role. They provide aesthetic interest in the form of vibrant colors and also act as scavengers cleaning up remaining soil contamination (Image source: http://lukemcreynolds.com/files/wallpaper/Grand_prismatic_spring.jpg).

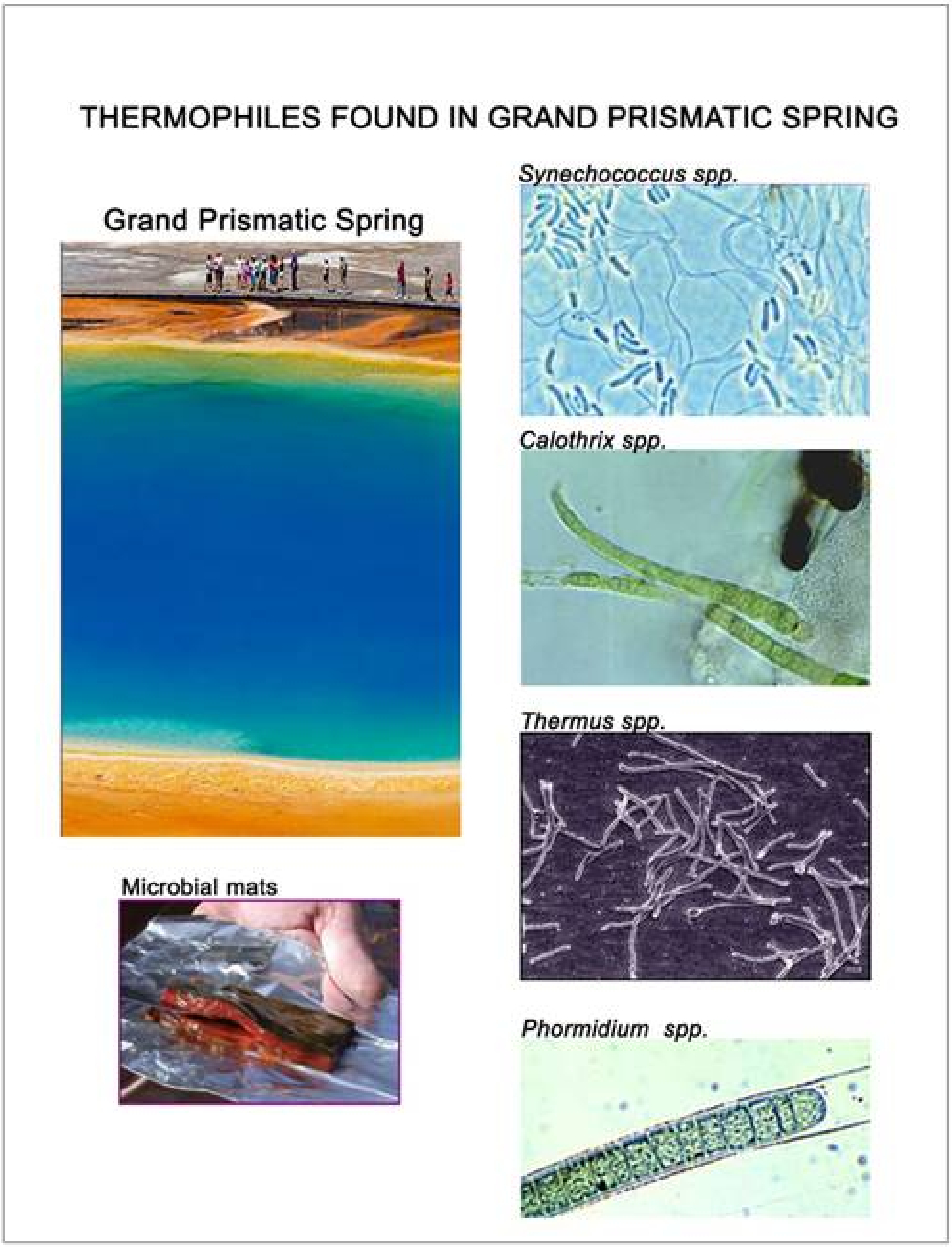



**Figure 23: Thermophiles found in Grand Prismatic Spring.** The figure shows most commonly found genera of bacteria and algae that impart colors to water in the Grand Prismatic Springs (Image source: Montage of images, all taken from Google Images).

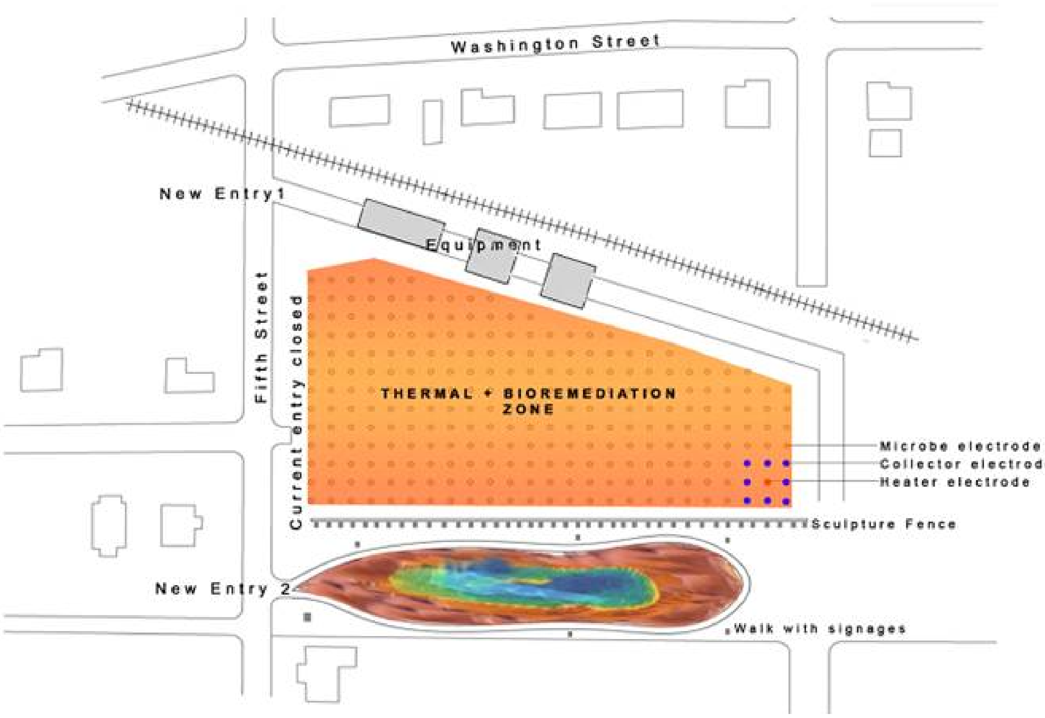



**Figure 24: Remediation design using DUS technology.** A part of immense heat produced below ground for DUS in the thermal zone can be harnessed to grow thermophiles to create a thermal pond; a temporary aesthetic feature on the site. It would give an opportunity for visitors to understand remediation processes and remediation design.

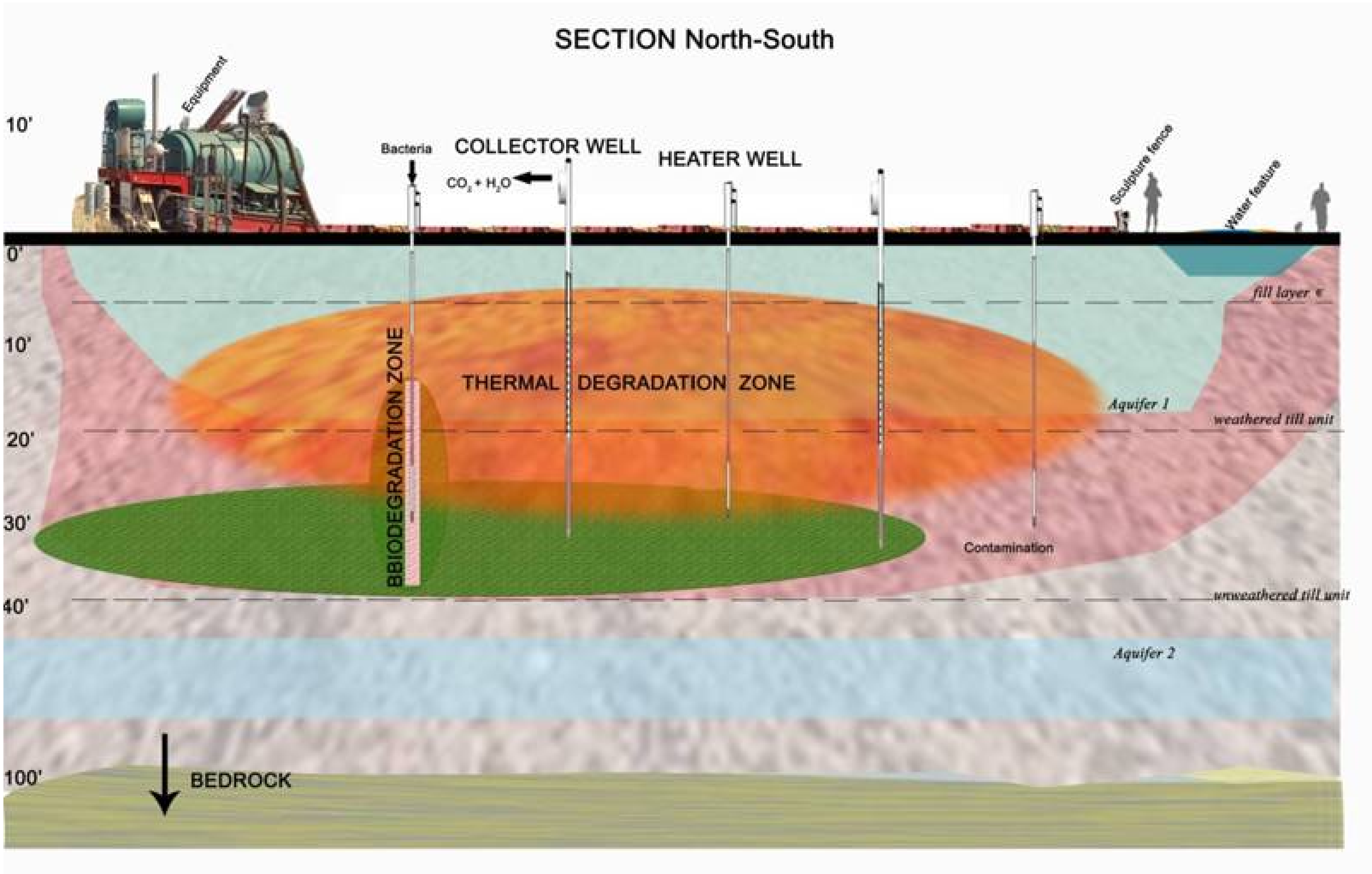



**Figure 25: Section of earth profile showing equipment and processes at work in DUS technology.** Heater wells placed at a definite distance heat the soil and create a thermal zone that bakes the soil and removes organic compounds. High temperatures are also used to activate the thermophilic bacteria that are inoculated through wells to create biodegradation zones. These bacteria scavenge remaining pollutants in the soil. Any carbon dioxide and water produced as a result of the thermal reactions is collected in collector wells (Image Adapted from Black, 2002).

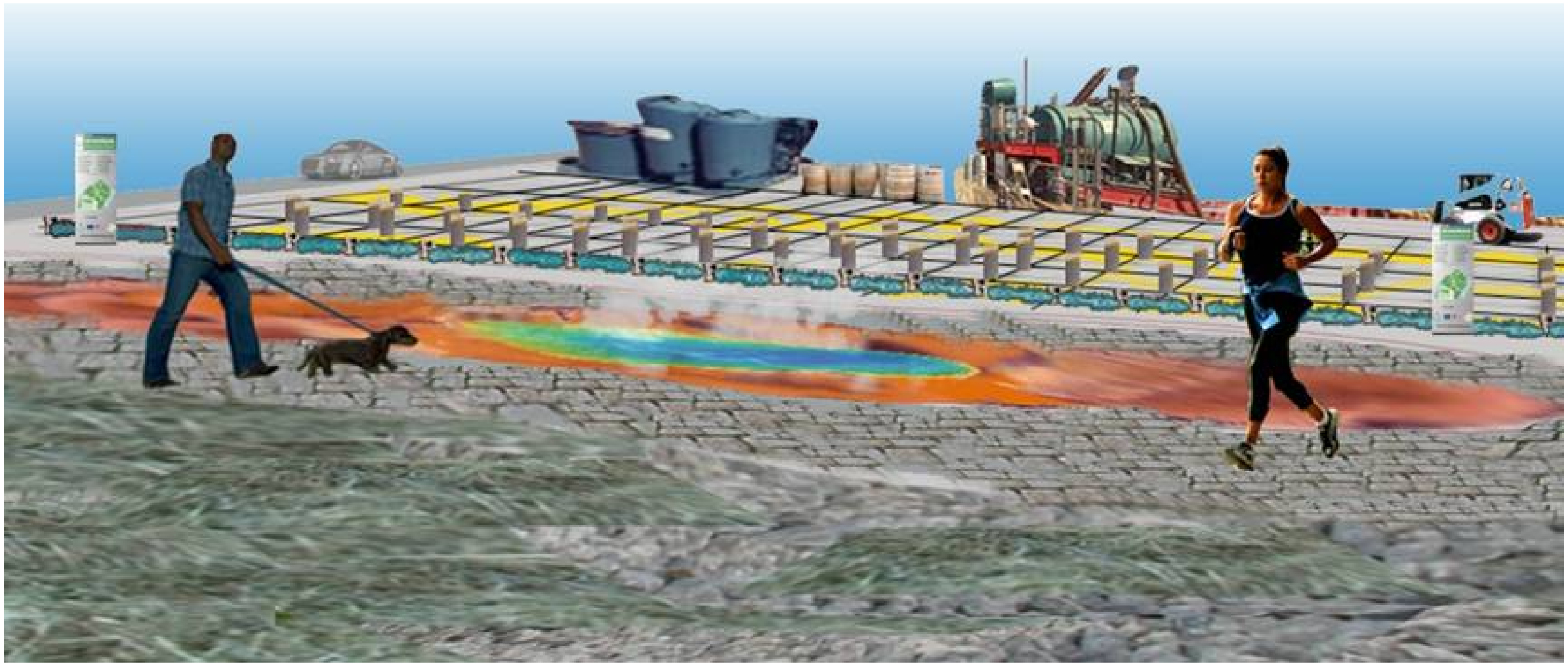


**Figure 26: Speculative Projection for Dynamic Underground Stripping Technology.** The figure illustrates the character of the site when it is being remediated with DUS technology. The site would become a point of attraction for the neighborhood and visitors due to construction of the thermal pond. The thermal pond however will be only work until the remediation processes are at work and provides a temporary solution to revealing remediation processes. It would also feature display boards giving information about remediation processes and the thermal pond.

**II. *In situ* Stabilization / Solidification:**

After the process of stabilization, concrete piers are typically covered with up to 5” soil. But I have proposed revelatory design to include elements of history and memory as part of the cleanup process. The concrete piers are brought 5’ above the ground and a foot print of the plant as it was in 1951 is recreated on the site. Bringing up concrete piers would reveal the remediation process, and displaying the site as it looked in the 1951 plan would be an interesting way to interpret it, teach about its history and relate to the past in a positive way.

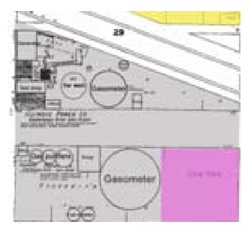
The design precedents were: Westergasfabriek culture park in Amsterdam designed by Kathryn Gustafson (Koekebakker, 2003), and Civil Rights Memorial designed by Maya Lin (Lin, 2000).

**Figure 27: Westergasfabriek culture park, Amsterdam.**
(Image source: http://www.westergasfabriek.nl)

**Figure 28: Civil Rights Memorial Montgomery, Alabama.** (Image source: http://en.wikipedia.org/wiki/Civil_Rights_Memorial)

**Figures 27 and 28:** Westergasfabriek Culture Park, Amsterdam and Civil Rights Memorial in Montgomery, Alabama were used as precedence for revealing the history of the site to the public by proposing places of gathering like in the culture park and embossed spaces like the embossed stone used for the civil rights memorial, and recreate the 1951 gas plant layout.

A ramp leads to the concrete piers; the remaining site is paved and also has embossed shapes giving information about the structures and their role in the production of manufactured gas. A gasometer was located south of Hill Street and I propose a similar looking structure at its place which can be used as a museum, art center and which could have a collection of historic photographs specific to site or information on manufactured gas plants and processes of production, newspaper articles, brochures, personal interpretations of visitors, their thoughts and feelings, narratives of the place from people associated with the site and so on. It could also exhibit local art and could be seen as a place for community to gather for special occasions. Since the site is entirely paved it would generate a large amount of storm water runoff. A storm water collection system is proposed that treats rain water falling on the site and is used to create a water feature.



1951 Plant
Lay out

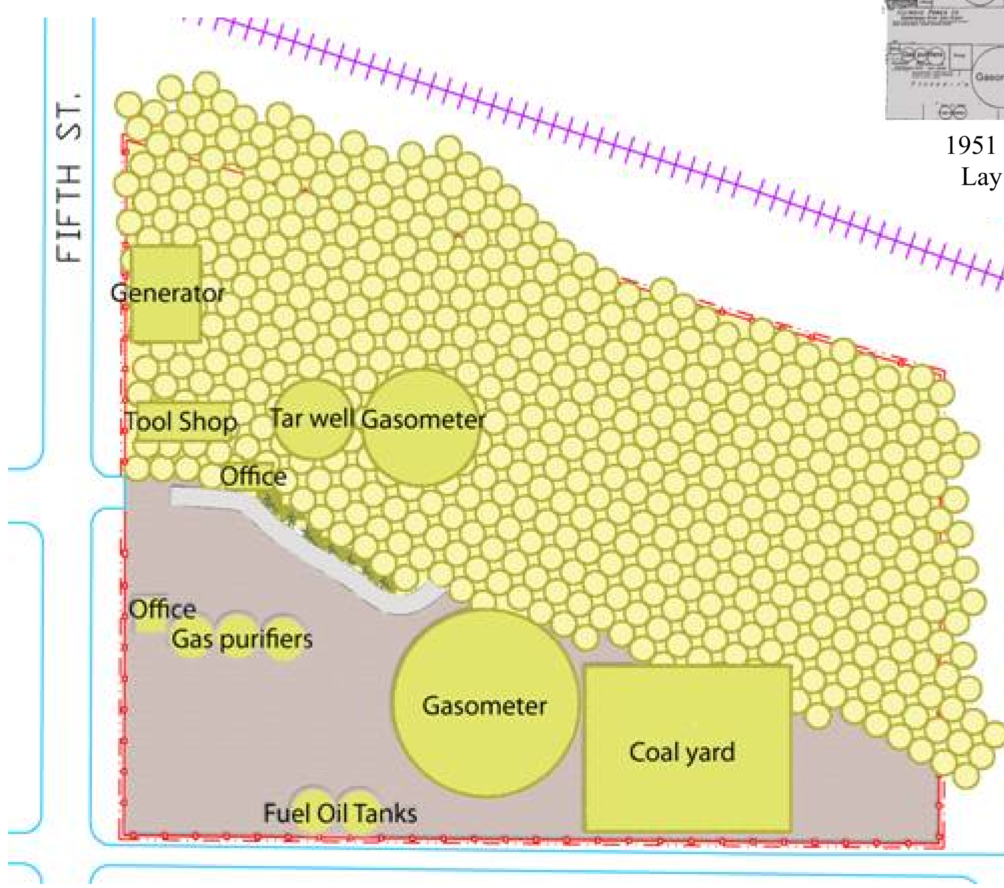



**Figure 29: Stabilization / Solidification design showing footprint.** A foot print of the MGP as in 1951 is recreated. A concrete ramp is used to access the piers after remediation. From the footprint, only the gasometer would be rebuilt to create a place for gathering and social interaction.

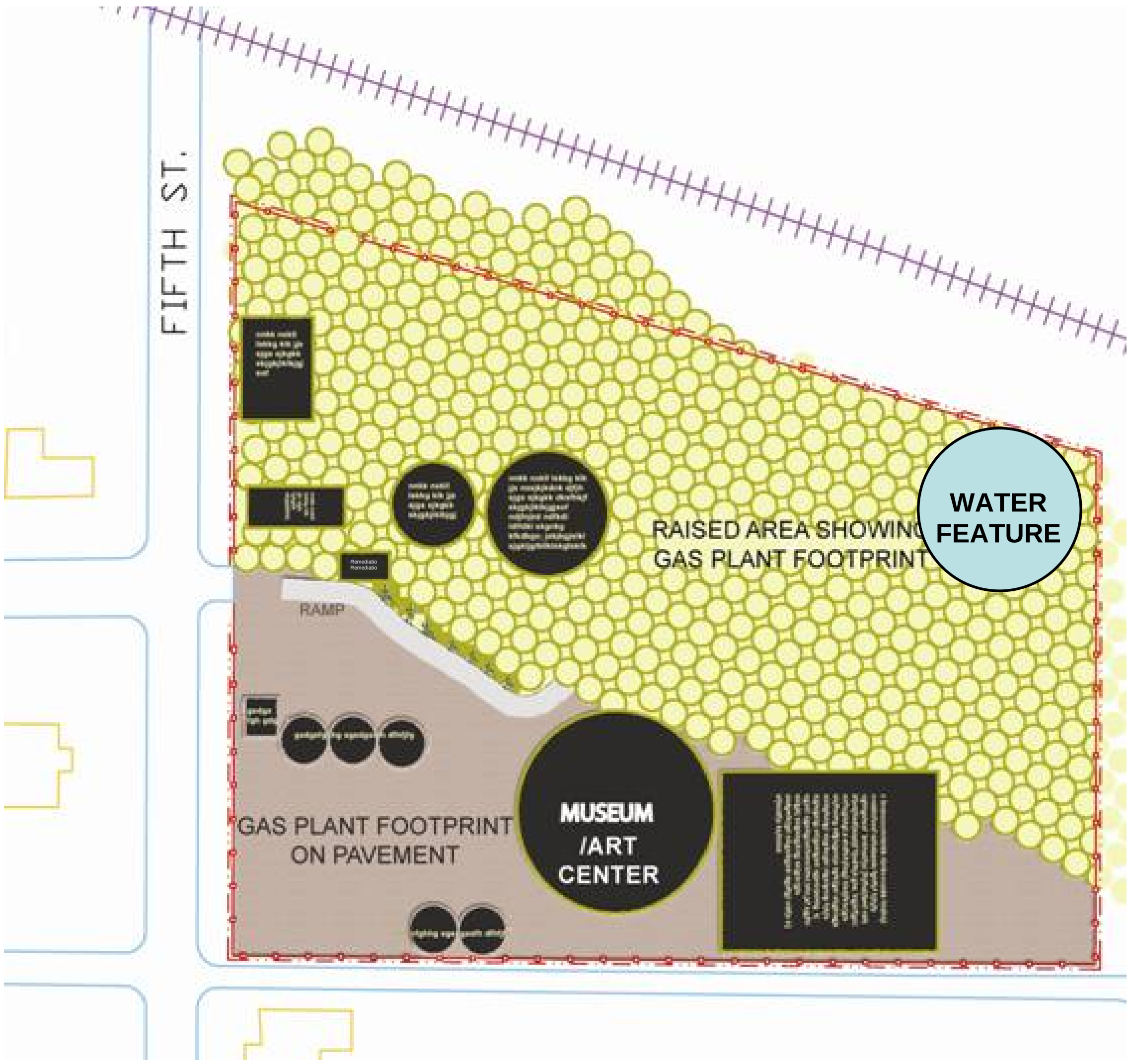



**Figure 30: Stabilization / Solidification design showing ramp, embossed spaces, art center, and water feature.** A foot print of the MGP as in 1951 is recreated using black granite, and structures and their utility in the MGP operation will be embossed in white. Since the site is entirely paved it would generate a large amount of storm water runoff. A storm water collection system is proposed that treats rain water falling on the site and is used to create a water feature. The museum/ art center will have the character and the feel of gasometers which would be initially used to retell the story of the site but as time progresses could be planned for various other uses like farmer's market, exhibitions, mini fairs etc.

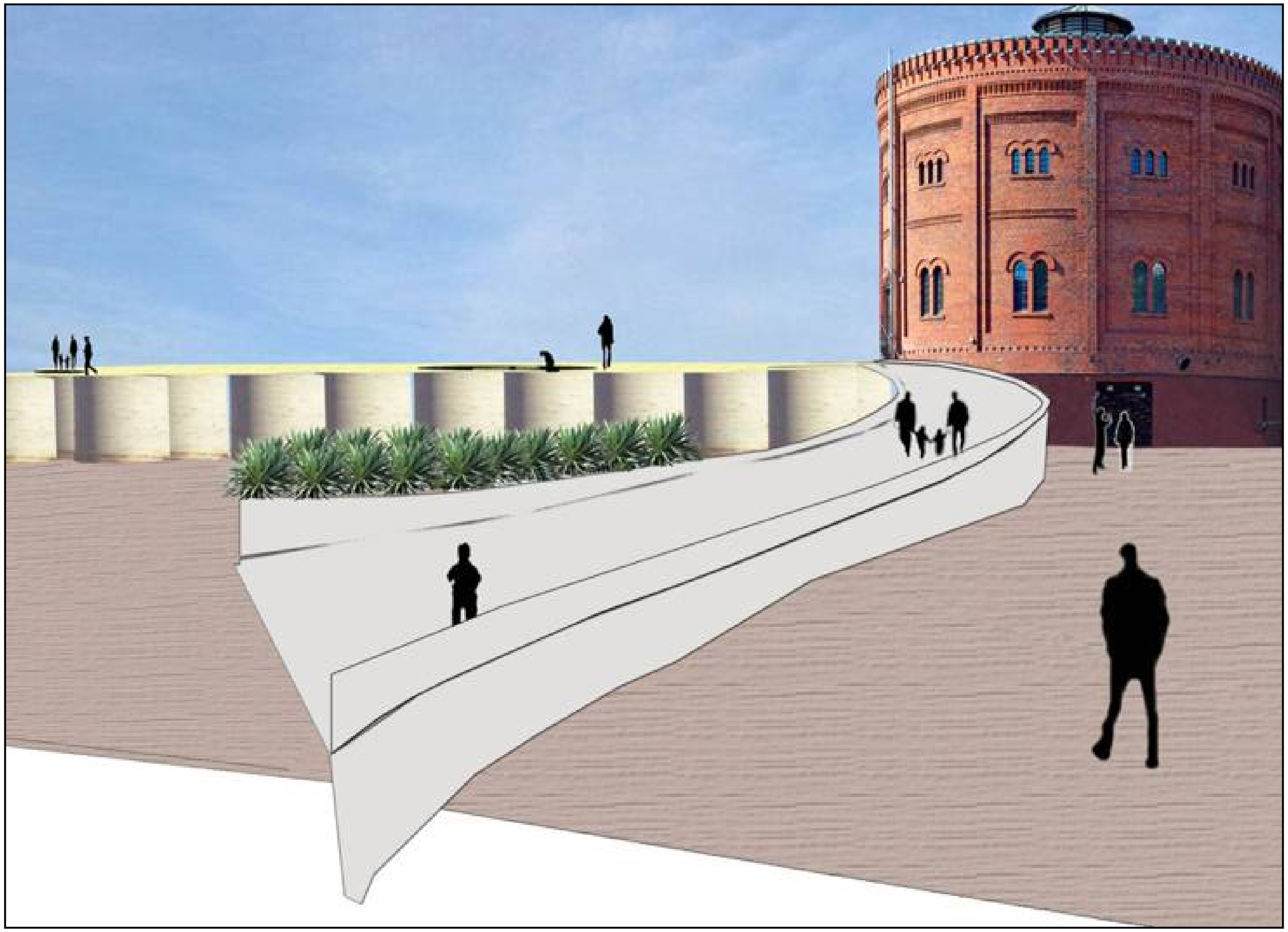


**Figure 31: Stabilization / Solidification speculative projection.** Site with raised concrete piers and a ramp leading to them is shown in the above figure. A gasometer like structure will be rebuilt where the gasometer stood before it was demolished and would be used as a space for indoor social interaction and recreation for the community.

These speculative projections are proposed to reveal the history as well as the remediation processes on the site. It is beyond the scope of this thesis to propose a 'particular' end use for the site after remediation. These projections are proposed to work only for some time; the thermal pond created during the functioning of DUS technology will only work until the period of remediation which is 6 months to a year. The concrete piers and the gasometer structure could be used for proposed activities for a long time but can also be removed to give way for other new developments on the site. After remediation, the site becomes a part of the urban fabric where end use is defined by the community.

**Regional consideration:**

To place the site in a regional context, towns are mapped along the railway line from Bloomington to Danville. The active rail line could create better opportunities of connecting people and places by offering an alternative to roads. This connectivity can also create numerous possibilities of connecting people to programmed and 'to be' programmed spaces that lie along this railway line to form an active recreation corridor.

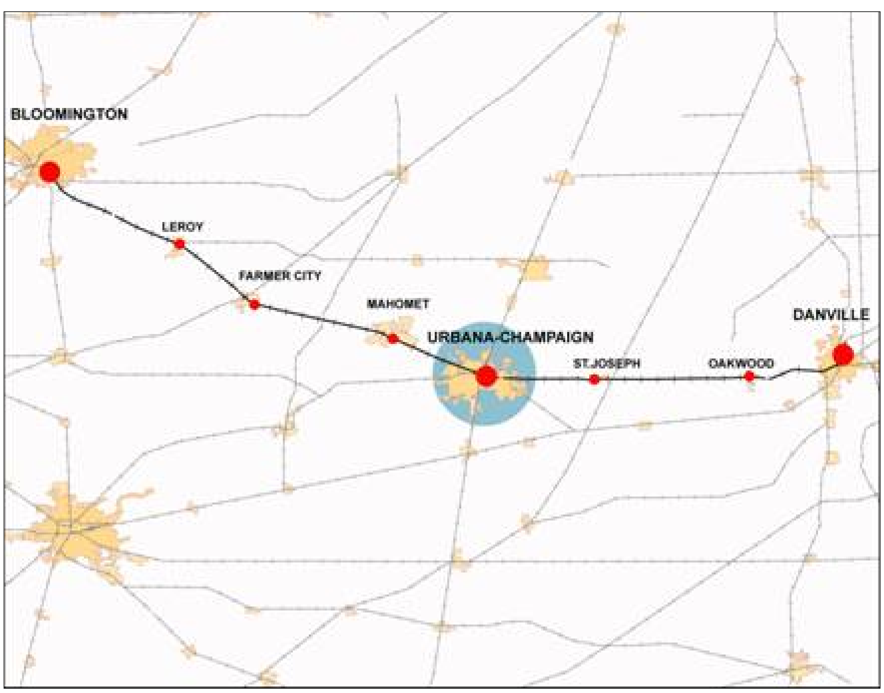



**Figure 32: Looking Beyond the site.**

Another approach for looking at the site with a broader context is to connect manufacturing gas plant sites in IL. The remediation technologies and revelatory designs proposed on the site in Champaign, IL can become a primer and an inspiration to the remediation and redevelopment of other manufacturing gas plant sites in IL and offer real or perceived connections to spaces creating networks of such sites.

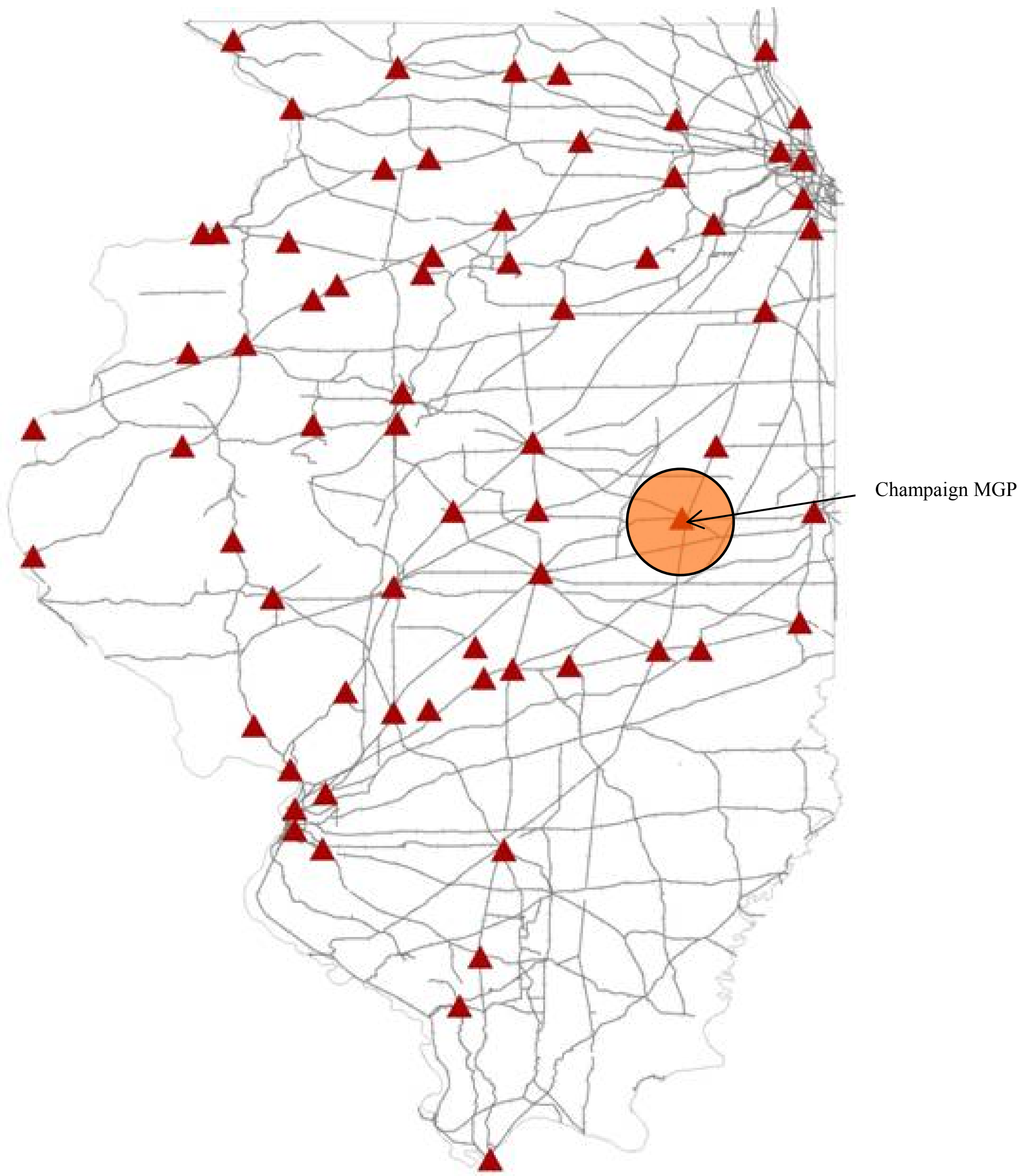



**Figure 33: Manufacturing gas plants in IL as documented by EPA.**

**Addressing social concerns:**

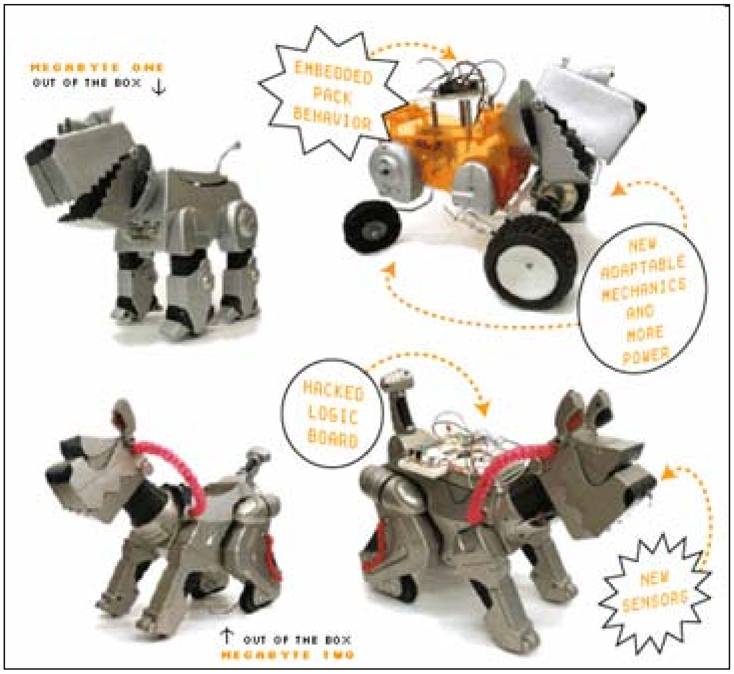



**Figure 34: Sensory equipment to detect presence of air pollutants.** Sensory equipments are proposed on the site to avoid possibilities of mishaps in the event of a failed remediation system. Figure 34 shows Natalie Jeremijenko's Robotic dogs that have VOC detecting sensors. Permanent sensors with remote information capability are also proposed on site. Products like these could be made available to visitors for their safety and their overall well being (Image source: http://www.interactivearchitecture.org/feral-robotic-dogs-natalie-jeremijenko.html).

Even though the objective of revelatory design is to increase awareness among people about brownfield as well as the history of the site, it is bound to create much anxiety among people in the vicinity of MGP sites about exposure to contaminants during or after remediation. Some products like Natalie Jeremijenko's robotic dogs that have VOC detecting sensors would be made available to visitors. Permanent sensors with remote information capability are also proposed on site. These would be connected to computer systems that give real time information on a designated website for example. This would avoid possibilities of mishaps in the event of a failed remediation system.

# Summary

Toxic sites like brownfields are often a source of debate and concern. There are also a number of myths and misunderstandings associated with such sites. As these toxic pieces of land have become an inherent part of the post industrial landscape, it is a responsibility of landscape architects working on such sites to elevate people's attention to get rid of the unrest and mystery attached to them. Currently, there is a complete lack of education and understanding of such sites among people as stakeholders usually tend to hide remediation activities and everything associated with them. The thesis however argues that this may not be the best way to handle the ubiquitous post- industrial landscape. On the contrary remediation itself may be used as an effective design and education tool for the general public. Remediation design serves two purposes; it connects people to their culture and the past and also educates them about remediation technologies used to remove contaminants that are a major concern for them.

Although remediation designs are essential to reveal the site to the public the most important task that needs to be dealt with, is the treatment technologies that remove deadly contaminants effectively. This forms a foundation ensuring safe reuse of the site. How the site is shaped after the remediation is only secondary. To that end, the MGP site contamination was studied thoroughly. Study of history and popularity of manufactured gas plants in United States, and the dynamics of growth and expansion of the site under study created a clear picture of the gas industry at the time. Careful study of the gas plant layout established links between structures and presence of contaminant hotspots observed onsite. Based on preliminary study and comparison with Ameren IP's clean up proposal, treatment technologies were screened for their effectiveness at addressing deep soil contamination, costs, duration, benefits and limitations. Ameren IP remediation plan included excavation, transportation and landfilling of contaminated soil. However this involves very expensive, unsustainable practices that would eventually lead to enormous environmental costs. Moreover, the contaminants are just transported with the soil and never treated. And at a time when the government is in a severe recession and when it appears that funding will be limited into the future, an approach with realistic solutions is warranted. Hence three *in situ* technologies; dynamic underground stripping, stabilization/solidification and landfarming were chosen for study. Emphasis of the study

was laid on *in situ* remediation techniques as they include minimal or no environmental costs. Most importantly, lifecycle analysis seldom considers the actual environmental costs associated with digging and dumping contaminated wastes in a different place. These include future treatment of the landfill site, potential contamination of the new area, its air, soil, ground water and potential health concern for inhabitants in that area. *In situ* remediation however avoids any further contamination and associated environmental costs.

Technologies were compared for their costs, duration and effectiveness. From this comparative study, the most suitable technology for the site was found to be stabilization/ solidification. The process of remediation using this technology takes around 6-8 months to complete and costs $ 4.5 million, which makes it not the cheapest but still the best one when the costs, duration and effectiveness of this technology are compared with other technologies. Two remediation technologies out of the three chosen for study were used further for speculative projections. These proposed revelatory designs being temporary have been proposed with an intention to draw the public to the site and to educate them about remediation processes.

Finally, the data in this thesis presented in a simplified manner is an attempt to reach out to a wider audience. It is intended for perusal by scientists and landscape architects alike. There is a growing need for collaborative work amongst these professions and it is imperative now that scientists involve designers or vice versa at the very beginning of such projects. The thesis strives to build an understanding about ways to deal with brownfield sites so that both professions can educate users about remediation processes and bring them closer to their culture and past through revelatory designs. Thus awareness among the public about toxic sites and their remediation would help build better landscapes, better spaces and better societies.

## Appendix A: List of Technical Definitions

**Grout:** A mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents; also, a mixture of other composition but of similar consistency. See also Neat Cement Grout and Sand Grout (www.pavement.com/glossary/g.html).

**Phytoremediation:** Phytoremediation describes the treatment of environmental problems (bioremediation) through the use of plants which mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere (http://en.wikipedia.org/wiki/Phytoremediation).

**Residue:** Residue (in chemistry) refers to the material remaining after a distillation or evaporation, or to a portion of a larger molecule, such as a methyl group. It may also refer to the undesired byproducts of a reaction (http://en.wikipedia.org/wiki/ Residue _%28 chemistry%29).

**Feedstock:** Raw material required for an industrial process (http://www.answers. com/ topic/feedstock).

**Wash water:** (*chemical engineering*) Water contacted with process streams (liquid or gas), packed beds, or filter cakes to flush or dissolve out impurities (http://www.answers .com/topic/wash-water).

**Effluent**: Effluent is liquid waste material that comes out of factories or sewage works (http://www.google.com/dictionary?aq=f&langpair=en|en&hl=en&q=effluent).

**Emulsion:** An emulsion is a liquid or cream which is a mixture of two or more liquids, such as oil and water, which do not naturally mix together (http://www.google.com/ dictionary?aq=f&langpair=en|en&q=emulsion&hl=en).

**Scrubber:** a purifier that removes impurities from a gas (http://www. answers. com/topic/scrubber).

**Adsorption:** The accumulation of gases or liquids on the surface of a solid or liquid (http://www.answers.com/topic/adsorption).

**Heavy metal:** A heavy metal is a metallic element with a high density. Many heavy metals are poisonous (http://www.google.com/dictionary aq=f&langpair =en|en&hl=en &q=heavy%20metal).

**Retorts:** A closed laboratory vessel with an outlet tube, used for distillation, sublimation, or decomposition by heat (http://www.thefreedictionary.com/retort).

**Hydrocarbons:** In organic chemistry, a hydrocarbon is an organic compound consisting entirely of hydrogen and carbon (http://en.wikipedia.org/wiki/Hydrocarbon).

Vadose zone: The vadose zone, also termed the unsaturated zone, is the portion of Earth between the land surface and the phreatic zone or zone of saturation ("vadose" is Latin for "shallow"). It extends from the top of the ground surface to the water table (http://en. wikipedia.org/wiki/Vadose_zone).

## Appendix B: List of Abbreviations

| | |
|---|---|
| MGP | Manufactured Gas Plant |
| FMGP | Former Manufactured Gas Plant |
| CSI | Comprehensive Site Investigation report |
| PAH | Poly aromatic hydrocarbons |
| RO | Remediation Objectives |
| TACO | Tiered Approach to Corrective Action Objectives |
| IEPA | Illinois Environmental Protection Agency |
| EPA | Environmental Protection Agency |
| SVOC | Semi-volatile Organic Compounds |
| VOC | Volatile Organic Compounds |
| Bgs | Below Ground Surface |
| BTEX | Benzene, Toluene, Ethyl Benzene, Xylene |
| SPH | Six Phase Heating |
| TPAH | Total PAH |

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